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Progress of Solar Technology and Potential Farm Uses

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Abstract

The most efficient use of solar energy on farms is space heating and cooling of livestock buildings, drying crops, and heating farm homes. Low-cost, homemade solar collectors, having multiple uses and a payback of less than 5 years, are the most popular systems. In contrast, most commercially produced systems are still too expensive for agricultural uses, partly because they fail to qualify for tax credits as large as those allowed for residential uses. The solar industry has shown little interest in marketing the low-cost technologies specifically developed for agriculture.

Keywords: Solar, agriculture, economics, research, development.

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Note

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Summary

Solar energy's modest but successful farm uses include crop drying and heating and cooling livestock buildings and farm homes. However, with interest rates of 15 to 20 percent, only solar energy systems with a payback of about 5 years are economically feasible. Solar collectors must be multipurpose and used for as many days as possible each year to absorb the investment.

Solar collector technology needs further research and development (R&D) as well as a delivery system for transferring the technology to farms. Problems persist in market penetration, testing, certification, and value determination of homemade collectors for lending and tax credit purposes. The solar industry has shown little interest in marketing the low-cost technologies specifically developed for agriculture by the public sector nor has the industry focused R&D on the needs of the agricultural sector. Thus, with declining Federal funding for research, solar energy's future in agriculture is uncertain.

This Economic Research Service report discusses the potential of solar energy for several agricultural applications:

Solar grain drying offers the most immediate potential for savings because storage and infield losses of high-moisture grain cut deeply into farm profits. Several hundred grain farmers who have invested in solar energy systems report paybacks of as little as 5 years. The potential for solar drying other crops, although promising, has not been fully researched.

Solar heated farrowing and nursery barns—perhaps the most popular use of solar energy in the Great Plains States—have an estimated payback at or near 5 years, when considering both space heating and cooling values.

Solar heated water for dairies is economical, but waste heat recovery from current systems costs even less. Consequently, solar energy has only limited potential here.

Solar heating houses for brooding broilers is not economical because of large variations in demand for solar space heat and the time the system lies idle.

Solar heating for greenhouses that grow vegetables and other items is less economical than energy conservation of fossil fuels. Fossil fuel requirements are reduced 90 percent when energy conservation is combined with solar energy. Solar energy accounts for around 10 percent of this reduction.

The potential of solar energy in agriculture is uncertain. Its role depends on future energy prices and the development of other alternate energy sources, such as nuclear and hydroelectric power, as well as the competitiveness of redesigned conventional power systems.

Progress of Solar Technology and Potential Farm Uses

Walter G. Heid, Jr.
Warren K. Trotter*

Introduction

The most efficient use of solar energy on farms is space heating and cooling of livestock buildings, drying crops, and heating farm homes. This study assesses progress in the development of economical solar energy systems and estimates the potential for their adoption in the agricultural sector. The primary focus is on solar collector systems, or direct solar thermal energy. Other solar energy technologies also are discussed where they appear to be acceptable alternatives to flat-plate collector systems. Farm activities are grouped according to energy needs to determine the potential for solar energy in agriculture.

This study summarizes nearly a decade of intensive solar research and development (R&D) aimed at agricultural applications. It cites many examples of progress and also identifies laboratory-designed solar collectors still needing field tests and economic evaluation. Public funding for solar R&D is undergoing major reductions. The content and conclusions of this study will be helpful to policymakers who must evaluate the ability of private industry to assume the leading role in developing direct solar thermal systems for agriculture.

Background

Events over the past decade suggest that future supplies of liquid fuels are highly uncertain and periodic shortages are likely to

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occur. Steadily increasing prices of all energy used on farms are seriously eroding farm profits and causing some farmers to seek alternate sources of energy. Solar energy is one alternative that can be substituted for stationary farm energy needs such as crop drying, space heating and ventilating the home and livestock buildings, and heating for poultry brooding, greenhouses, and water. Farmers have the rare capability to adapt technologies developed for two markets—residential and agricultural.

Since the midseventies, the solar energy industry has developed rapidly, and today, a large number of firms are engaged in the manufacture and sale of solar energy systems. Private industry and government researchers have evaluated residential and commercial solar technologies, and have identified the best engineered and most economical designs. The use of solar energy for certain applications, particularly residential space heating and water heating, is becoming well established.

Many earlier industry problems, related to product quality and dealer reliability, are being solved. Commercially manufactured collectors now are being tested and labeled, enabling consumers to identify workable solar collector systems. Dependable sales and service firms are emerging. Also, Federal and State incentives, largely financial, are offering encouragement to buyers. Commercial solar devices, developed largely for the residential market, are applicable to farm homes and, possibly, a few other farm uses. However, current manufactured collector prices discourage most farm uses.

A large, publicly supported agricultural solar R&D program has been ongoing since the early seventies. This program, conducted largely by the U.S. Department of Agriculture (USDA) and land-grant colleges, has produced numerous promising systems and applications. These systems, mostly homemade, involve solar collectors designed for both single and multiple uses. Attention has been focused mostly on low-cost systems. Farmers can often use materials available on the farm to construct collectors designed in this research program.

The agricultural solar program has produced solar collectors competitive with conventional energy costs, but many proposed designs still need further testing and economic evaluation. A major educational program is yet to be launched.[1]

Farmers account for most of the solar collector systems in use, and these systems are receiving wide acceptance in some areas or communities where active solar promotion programs exist. Generally, however, the rate of adoption is slow because of the lack of an organized system for transferring solar technology from laboratories to farmers, high interest rates on borrowed capital, low cash flows, and plentiful conventional fuels. Farmers will need a reversal of the above reasons, plus the improved economic competitiveness of solar devices, before widely accepting solar devices.

Energy Use in Agriculture

Energy used in U.S. agriculture was estimated to be about 2 quads in 1980, or nearly 2.5 percent of U.S. energy consumption.[2] About two-thirds of this amount was used directly on farms. One-third was used in the manufacture of fertilizer, fuel, and pesticides *(96)*.[3] The four major uses of energy in agricultural production are petrochemicals, irrigation, transportation of products, and power for field machinery (fig. 1).

Farm use of the three major fuels—diesel, gasoline, and liquid petroleum gas (LP)—totaled an estimated 8.1 billion gallons in 1979 (table 1). Diesel fuel use is increasing as farmers replace old gasoline-powered machines with more energy efficient diesel machinery. Over the 5-year period, 1975-79, USDA estimates showed a 1-billion gallon onfarm switch from gasoline to diesel.

[1]The commercialization program sponsored by the U.S. Department of Energy (DOE) has focused on the commercial and residential sectors.

[2]A quad is one quadrillion (10^{15}) British thermal units (Btu) of energy. One quad of energy is enough to heat 500,000 homes for 20 years, or enough crude oil to fill a fleet of 75 supertankers (weighing 325,000 tons), each with a capacity of 2.5 million barrels of oil.

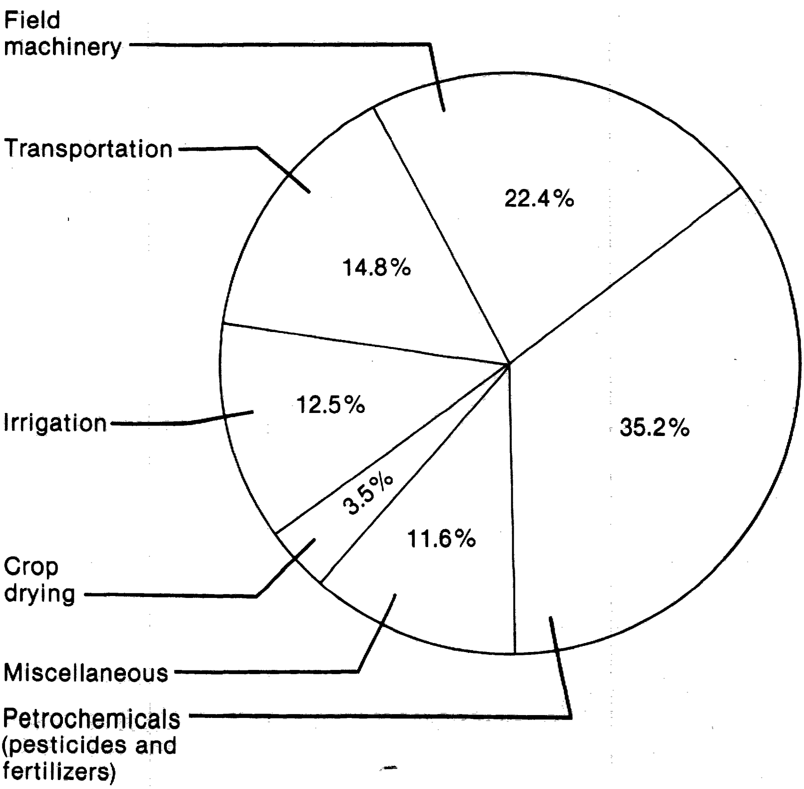
[3]Italic numbers in parentheses refer to the sources listed in the Bibliography.

This trend, which gradually occurred over the decade, made diesel engines the most common agricultural power source by 1980.

Energy use in agricultural production is increasing very slowly. This trend developed since the early seventies as: (1) narrowing profit margins forced farmers to conserve fuel, (2) the number of cropland acres remained about constant, (3) no significant

Figure 1

Percentage of Energy Used in Agricultural Production by Function



Source: (96).

Table 1—U.S. farm fuel use[1]

Fuel	Unit	1974	1975	1976	1977	1978	1979
Gasoline	Bil. gal.	3.7	4.4	3.9	3.8	3.5	3.4
Diesel	do.	2.6	2.4	2.8	2.9	3.3	3.4
LP gas	do.	1.4	1.0	1.0	1.1	1.5	1.3
Electricity	Bil. kWh	30.3	31.8	35.8	35.5	35.5	35.6

[1]Includes farm residence use.

Source: *(96)*

increase occurred in livestock numbers, (4) large farms successfully employed economies of scale in fuel use, and (5) more fuel efficient equipment was purchased.

An estimated 35.6 billion kilowatthours (kWh) of electricity were consumed on the farm in 1979 (see table 1). Electricity use nearly doubled between 1964 and 1976. Although the estimates in table 1 indicate that the use of electricity has remained nearly constant since 1976, other sources suggest that its use has continued to increase.

In terms of Btu, fuels were consumed in 1979 as follows *(96, 97)*:

Fuel type	Btu (trillion)[4]
Gasoline (124,300 Btu/gallon)	422.6
LP gas (92,000 Btu/gallon)	119.6
Diesel (139,000 Btu/gallon)	472.6
Electricity (3,412 Btu/kWh)	121.6
Total	1,136.4

The average U.S. farm uses about 934 million Btu of energy annually. The farm business accounts for 84 percent of the

[4]The difference between this estimate of approximately 1 quad and the DOE estimate of 2 quads used on farms in 1980 is the omission of natural gas and fuel oil used on farms and indirect uses of energy in the form of petrochemicals, principally fertilizers and pesticides.

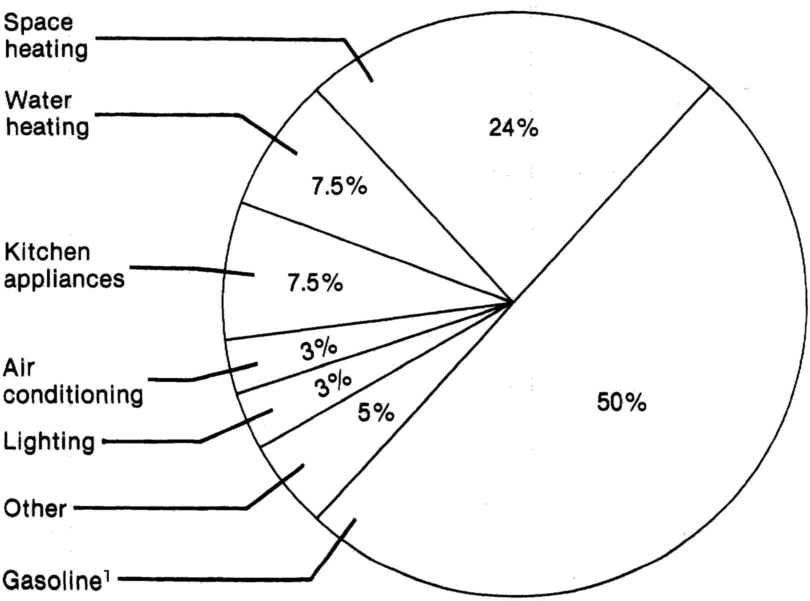
amount, and the farm home 16 percent. A breakdown of total personal energy consumption, including the use of automobiles and light trucks, is shown in figure 2.

The volume of electricity, natural gas, and LP gas used on farms is particularly important when considering solar technology because these often represent stationary fuel uses, for which solar energy may be substituted.

About 70 percent of all farm electricity consumption is used in the farm residence. Gasoline accounts for about 50 percent of total personal farm energy consumption (fig. 2). This percentage should decrease as farmers buy more energy efficient cars and

Figure 2

Total Personal Farm Energy Consumption



[1]For automobiles and light trucks.
Source: (95); adjusted for average personal farm transportation.

trucks. For a farm family having only energy efficient vehicles, this percentage may be nearer 34 percent of the total.

In the 5-year period 1976-80, the price for natural gas increased far more than the prices of gasoline, diesel, and LP gas (table 2). Natural gas, however, is still much cheaper per million Btu than gasoline, diesel, and electricity. However, natural gas deregulation could bring that fuel's price even closer to solar costs. Natural gas price increases will, of course, enhance the growth of the solar industry in both agriculture and the residential sector since direct solar thermal energy adapts well as a replacement.

Farm energy use in 1990 and beyond will likely be greater than the 2 quadrillion Btu estimated by Gavett in 1978, since by 1980, total consumption had already exceeded his estimate (table 3)

Table 2—Selected fuels and energy prices, 1976-81

Energy source	1976	1977	1978	1979	1980	1981
			Cents per gallon			
Farm uses:						
Gasoline, bulk delivery (leaded regular)	54.2	57.8	60.0	83.1	118.0	129.0
Diesel fuel	41.7	45.0	46.0	72.2	101.0	118.0
LP gas, bulk delivery	36.2	39.1	40.1	43.5	61.7	69.9
			Cents per 1,000 cubic feet			
Residential uses:						
Natural gas	0.104	0.226	0.263	0.323	0.392	[1]0.440 to 0.463
			Cents per kWh			
Electricity	3.7	4.0	4.3	4.6	5.4	[1]5.7 to 6.0

[1]Projected.

Sources: *(94, 106)*.

(30). Gavett's estimate assumed an 18.6-percent increase in farm output per unit of energy input and a 20-percent increase in production. During 1978-80, U.S. grain crop acreage increased 6.2 percent, and wheat acreage increased 22 percent. Thus, even shortrun energy use projections are difficult due to such instability in crop acreage, especially since all crops do not require the same amount of energy per acre.

Estimates of future population provide more certain evidence of future energy needs since energy is also related to units of farm output. If a 50-percent increase in worldwide population should occur between 1980 and the year 2000, as some projections indicate, the use of energy for livestock production and crop drying is likely to increase accordingly. Energy use increases for livestock production and crop drying will be significant because they include large amounts of LP gas and electricity, two types of energy for which direct thermal solar energy may be substituted.

Table 3—U.S. energy used in farm production[1]

Use	Production in 1990	Percentage change from 1974 to 1990
	Trillion Btu	*Percent*
Chemicals	866	21
Livestock	256	14
Transportation	231	- 9
Irrigation	193	-26
Preharvest fieldwork	176	-29
Harvest	122	-13
Crop drying	143	34
Total	2,044	2

[1]Assumes farm output per unit of energy input will be increased by 18.6 percent, and the continuing trend toward a different mix of fuels, better production practices, and increasing yields.

Source: *(30)*.

Promising Solar Technology Applications

The solar applications in this report were selected because they were part of a partial economic evaluation or appeared to be a promising technology. In some cases, an economic evaluation still is needed to guide development of the technology. Though this report concentrates on the more promising technologies, the literature contains numerous studies that show the use of solar energy in agriculture to be impractical.

Crop Drying

Research indicates that solar crop drying is economically feasible, given well-designed systems and multiple farm uses. Solar drying systems show a payback of 3.5 to just over 5 years.

Several major crops are artificially dried. Artificial drying, adopted by farmers during low energy prices and plentiful supplies, reduces field and storage losses. Field losses may run as high as 20 percent for some grain crops if they are left in the field until they mature enough for safe storage. Storage of high-moisture crops may result in even greater losses.[5] Thus, artificial drying annually saves millions of tons of grain and other crops.

Artificial drying is energy intensive; increased energy prices make it an expensive practice. These factors have led to an extensive search for alternate crop-drying methods—the use of direct solar thermal energy, photovoltaics, various biomass fuels, and wind—as well as more energy efficient conventional drying systems.

More than 100,000 crop dryers are used in the United States. Most of these dry corn and rice. About 730 million gallons of LP gas equivalent is used annually for crop drying, and over 90 percent of this amount is used for drying corn *(92)*.

[5]This statement excludes the storage of crops in facilities designed for high-moisture grain.

Most direct solar thermal energy research has centered on the development of air-type, flat-plate solar collectors and dedicated (single-purpose) drying systems for specific types of crops, such as grain, peanuts, tobacco, hay, and hops. Considerable knowledge of these dedicated systems was gained during the seventies. As this research continues, more attention is being focused on multiple-use designs so that fixed costs per unit of usable solar energy output can be reduced.

Research shows that flat-plate solar collectors have economic potential for crop drying. However, to achieve a reasonable payback, farmers should consider portable multiple-use collectors. It is more practical to move a collector between uses than to heat through ducts over long distances from a stationary collector. Long-distance ducting (50 to 100 feet) results in an extensive loss of heat. Unlike some European farmsteads, U.S. livestock buildings, grain bins, and farm shops are usually located 100 feet or more from the farm home and frequently that far from one another. However, there may be side-by-side uses. If, for example, a grain bin were located adjacent to a farm shop or livestock building, a roof or wall-mounted collector could serve both buildings very efficiently. Solar collectors built into the roof or wall of new structures are normally less expensive but still should be used for more than one purpose whenever possible.

A difficulty confronted by researchers attempting to design multiple-use solar collectors for crop drying and other uses lies in the variance in airflow and heat requirements. Designing a multipurpose solar collector is like building a multipurpose water reservoir. A reservoir cannot be 100-percent effective for flood control if another purpose is for recreation or hydroelectric power.

Grain Drying. Low-temperature grain drying, a slow method highly dependent on low relative humidity, must be managed with extreme care *(41, 61)*. Danger of grain spoilage persists, especially in upper-bin drying zones.

Much was learned during the seventies about system design and solar collector efficiency for grain drying. Liquid-type collectors, requiring a heat exchanger, were found to be less efficient than air-type collectors. Concentrating collectors, generating heat to over 2,000°F, appeared to be too complicated, too difficult to build in farm shops, and too expensive to purchase. Engineering research largely eliminated such designs as the short-life inflated tube collectors and the rock heat storage collectors. Research has also shown the technical and economic limitations of using solar energy to dry high-moisture grain *(35, 90).*

From an engineer's viewpoint, solar energy may safely dry high-moisture grain if used on a grain-drying bin equipped with a stirrer; if used to preheat the inlet air to high-temperature dryers; or, if accompanied by a backup unit that can be used in years of high humidity and low insolation (incoming solar radiation) at drying time. However, from an economist's standpoint, each of these alternatives is costly. The reward for high-quality grain in the marketplace is so low that farmers cannot afford to use stirrers or a dual-drying system. One study indicates that farmers are financially ahead to let their corn occasionally deteriorate from grade No. 2 to grade No. 3 rather than own a backup unit *(35).* This same study found that in poor drying years the grain spoiled even with added solar heat. These results of a simulation study suggest that solar drying should be limited to intermediate-moisture grain.

Solar collectors can be used to overdry corn held in storage. The overdried old corn is blended with high-moisture new corn. Still another use of old corn is as a heat storage medium by solar heating it in the daytime and drawing heat from it at night to dry the new corn. If old corn is kept on the farm for blending or as a heat storage medium it cannot be marketed until new corn drying is completed. These practices may be technically feasible, but they should be closely scrutinized. Neither cash flow position nor corn price levels may be stable enough to permit yearly dependence on them.

Kline and Odekirk compared three drying systems—an electric resistance heater, an electric resistance heater supplemented by solar heat, and a solar collector that served as the only source of supplemental heat (50). Six prototype collectors were used to estimate costs and performance. The costs ranged from $10.90 per million Btu to $37.88 per million Btu (table 4). A comparison of the present value of supplemental heat costs of the three drying systems showed that none of the selected solar collectors could compete economically with electric heat (table 5). Electric energy was saved when electric resistance heaters were supplemented with solar energy, but the effect of higher initial investment costs and maintenance costs outweighed the electric energy savings. The collectors used in this study were low-cost, short-life structures. No multiple uses for the collectors were considered.

Shove mounted solar collectors on the wall of an Illinois farm machine shed (76). He then placed aluminized plastic reflectors on wooden frames in front of the collectors to measure output.

Table 4—Total cost of solar energy collected, solar grain-drying experiments

Collector number	Estimated life	Period one[1]	Period two[2]	Combined drying periods[3]
	Years	*Dollars/million Btu*		
1	5	21.38	24.82	23.10
2	5	13.47	15.12	14.30
3	8	35.70	40.07	37.88
4	8	10.27	11.53	10.90
5	10	17.13	19.22	18.18
6	10	14.92	16.74	15.83

[1]Mid-October to mid-November drying period.
[2]Month of November drying period
[3]Over the life of each collector, 50 percent of the corn is dried in each drying period.

Source: (50).

Table 5—Present value of supplemental heat costs, solar-grain drying experiments[1]

Collector number	Estimated life	Period 1[2] Electric	Period 1[2] Solar electric	Period 1[2] Solar	Period 2[3] Electric	Period 2[3] Solar electric	Period 2[3] Solar
	Years	*Dollars*					
1	5	1,521*	1,972	5,542	1,521*	1,991	6,365
2	5	1,521*	1,947	3,056	1,521*	1,984	3,441
3	8	2,380*	3,067	[4]	2,380*	3,084	[4]
4	8	2,380*	2,720	3,317	2,380*	2,786	3,737
5	10	2,930*	3,946	5,521	2,930*	4,038	6,494
6	10	2,930*	3,668	4,917	2,930*	3,767	5,791

*Lowest cost alternative.
[1]Assumed 8-percent yearly increase in electrical rates.
[2]Mid-October to mid-November drying period.
[3]Month of November drying period.
[4]Impractical, since 27 and 30 units, respectively, would be required to finish drying.

Source: *(50)*.

This solar collector system had an annual cost of about 1 cent per bushel more than an LP gas-drying system.

Costs	Solar drying (dollars per bushel)	LP gas drying (dollars per bushel)
Fixed	$0.069	$0.049
Variable	.030	.039
Total	$ .099	$ .088

However, an energy consumption comparison showed that the solar system used 4,876 Btu per bushel less energy than the LP gas-drying system:

Solar drying (Btu per bushel)	LP gas drying (Btu per bushel)
2,457	7,333

The total energy saved on 25,000 bushels of solar-dried corn was equal to 1,333 gallons of LP gas at the time of the 1978 study.

Hellickson used a 412-ft^2 intensifier-thermal energy storage system to solar dry corn in South Dakota *(36)*. The system provided the equivalent of 629 kWh of energy over a 19-day period. The rise in collector temperature averaged 37°F, and system efficiency was 33.4 percent. Designed for multiple uses, the system also was used to preheat the ventilation air for a swine-finishing building. In 27 days during January and February 1981, the collector having an average temperature rise of 49°F and an average efficiency of 32.5 percent added an equivalent of 1,064 kWh to the ventilation air. An economic assessment of the performance of this system indicates that it is competitive with conventional fuels when used for both crop drying and livestock building heating.[6]

[6]Plans and specifications for this system are available. Write to the Agricultural Engineering Dept., South Dakota State Univ., Brookings, S. Dak. 57007. Specify "SEI-TES system plans." The cost is $4 per set.

Generally, for solar grain drying to be economical, farmers must have other uses for their collectors. Heid evaluated a promising solar collector design for multiple agricultural uses in 1981 *(34)*. The collector, built by a Nebraska farmer, incorporated three important features: flexible airflow, portability, and tiltability. Estimated payback was 5.8 years.[7]

Scientists at the University of Illinois also have designed a multiple-use portable collector. The 228-ft^2 collector is designed at a 60° slope, and is intended primarily for heating air for crop drying, but can be used for preheating fresh air for livestock shelter ventilation or for heating a farm shop. The basic collector, excluding ducts, fan, and skids, could be constructed for $1,045 (1979 dollars), or $3.63 per ft^2. As of October 1981, more than 5,000 copies of this plan had been sold by the university.[8]

Solar collectors of these and other designs are beginning to penetrate the farm grain-drying market. Although the exact number is not known, by 1980, several hundred farmers had invested in solar collectors to dry grain, including 300 in Illinois. Generally, farmers experimenting with solar grain drying are satisfied with fossil fuel savings, and geographic pockets of acceptance are growing.

USDA initiated a solar grain-drying farm demonstration project in 1980 in light of the R&D progress in low-cost solar collector design and the growing rate of acceptance by farmers. Objectives of the project included: (1) demonstrating the technical and economic feasibility of using solar energy for drying and other supplemental uses, (2) minimizing the interruption or interference in the normal operation of the drying facility, and (3) identifying the incentives and opportunities for widespread farm application of solar energy technology. About 90 farmers are participating in this solar demonstration project.

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[7]Plans for this collector are available from the Small Farm Energy Project, P.O. Box 736, Hartington, Nebr. 68739. Specify "Portable Solar Collector Plans." The cost is $3 per set.

[8]Plans for this collector are available from the Dept. of Agr. Engr., Univ. of Illinois, Urbana-Champaign, Ill. 61801. Specify "Illinois Plan No. SP-546 Portable Solar Collector." The cost is $1 per set.

Hop Drying. Kranzler tested two types of solar collectors at Washington State University *(51)*. For each experiment, a homemade collector was compared to a commercial collector. Also, each collector was tested assuming three uses: preheating, recirculation, and multiple use. In the preheating test, the collectors were used to heat a portion of the conventional furnace intake air. In the recirculation test conducted on only collector I, its uses focused on conditioning exhaust air from the hop bed before returning it through the drying furnace to dry hop residue (table 6). In most of his tests, Kranzler found that solar hop drying was uneconomical at present fuel prices. However, when a 15-percent energy cost escalation and/or multiple uses were assumed, favorable economic returns were projected. Payback ranged from 3.5 years to 18 years.

Hop drying is a short-season activity, extending only from mid-August to mid-September. Therefore, multiple uses are required to make this system economical. Plans call for solar heating a nearby greenhouse to shorten the payback in future experiments. Collectors used for hop drying may also be used for grain drying and home heating. However, to achieve the desired multiple uses, portable solar collectors for hop drying may be necessary.

Table 6—Payback periods for solar hop drying, 1980

Collector use	Collector I		Collector II	
	Farmer installed	Contractor installed	Farmer installed	Contractor installed
	Years			
Preheating	18.0	—	11.5	18.0
Recirculating	9.0	15.0	—	—
Multiple use	5.5	9.0	3.5	6.0

— = Not tested.

Source: *(51)*.

Hay Drying. Large round hay bales are being dried experimentally by scientists at the universities of Illinois and Tennessee *(9, 62)*. Low-density large rectangular hay stacks are also included in the Tennessee research. Both experiments test solar collectors mounted as structural components of hay-drying barns and portable, or free-standing, devices.

Results of the research suggest that solar hay drying has potential uses. The Tennessee experiments concluded that supplemental heat storage is needed and that low-density, or hollow bales, would improve the performance of solar bale dryers. Tennessee researchers are currently combining solar hay curing with grain drying and farm-shop space heating. Their system also appears to be suitable for curing tobacco or peanuts by using drying wagons.

In the Illinois experiments, solar-heated bales were dried to a lower final average moisture content than unheated air-dried bales. Overdrying of the bottom portion of the solar dried bales was a problem. However, the solar-dried bales required 20-percent less fan energy per percentage point of moisture removed than the unheated air-dried bales.

Neither study included an economic analysis. However, the similarities of hay drying and grain drying—capital investment costs associated with solar drying, the low premium received by farmers for high quality products, and the shortness of drying periods—suggest that solar hay curing, alone, is not economical. Fortunately, the demand for hay drying, like hop drying, comes in the summer and does not conflict with grain-drying or space-heating needs. Thus, hay drying may become economical if the capital investment for solar-drying equipment can be amortized over more than one farm production activity.

Peanut Curing. The moisture content of freshly dug peanuts ranges from 30 to 35 percent and must be reduced to 8 to 10 percent for safe storage. Normally, peanuts are left in windrows for several days after digging to partially dry in the sun before being combined and loaded into drying wagons. The wagons are designed so that they can be attached to a mechanical dryer to complete the drying process without being unloaded. The rate of moisture removal is a critical factor. If moisture is removed too slowly, mold growth may occur; if it is removed too rapidly, the physical or chemical quality of peanuts may be altered. Either extreme may reduce peanut quality. Peanuts containing aflatoxin, a byproduct of mold growth, must be used for oil stock. The meal from such peanuts is restricted to fertilizer use. The mold problem has prompted a trend toward eliminating windrow drying and going directly to artificial drying procedures.

Presently, most peanuts receive some artificial drying, usually with LP gas. Depending on the amount of moisture to be removed and outside (ambient) air temperature, the quantity of LP gas required may vary from 4 to 10 gallons per ton. Assuming an average of 6 gallons per ton, the 2 million tons of peanuts produced in 1979 would have required 12 million gallons of LP gas for curing.

Butler and Troeger experimented with air- and liquid-type solar collectors and heat storage systems for curing peanuts *(10)*. The collector systems were built as structural components of a multipurpose drying shed roof. Both used LP gas for backup heat. Rock and water storage structures were placed under the shed. The air/rock heat storage system initial investment was least costly. Freezing and corrosion problems were limited, and damage from leaks was eliminated.

In a series of commercial scale tests, the air-type solar system provided 74 percent of the energy used throughout the season, and sometimes provided 100 percent of the heat used for drying. Drying rates were similar for the solar and the conventional LP gas dryer, and peanut quality differed little. Operating costs of the system are not yet available.

Huang and others have developed a solar peanut-drying system to be used with their multipurpose greenhouse bulk-curing barn *(45)*. The system is a rotary drum dryer designed to be mounted on a trailer for field loading much like a conventional peanut wagon. The trailer is moved into the greenhouse for solar curing and drying. The outer shell of the drum is made of perforated metal which acts as the absorber plate. During daytime, the drum surface continually collects solar energy to heat the air flowing through the peanuts that are drying inside the drum. The rotary drum unit can also be used to dry other crops.

Schlag and Sheppard constructed and tested several types of low-cost solar collector and storage systems to determine their suitability for peanut curing *(73)*. The augmented integrated rock system is one of their most promising discoveries. This system has a 720-ft^2, black film, hot-air collector connected to a 480-ft^2 integrated rock storage structure. The cost of the 1,200-ft^2 system was estimated at $1.50 per square foot of collector area. Construction and maintenance requirements were kept as simple as possible. Cost savings on 72 tons of peanuts over the conventional curing system was estimated to be $73 a year. The system may be used for other crop-drying applications.

Person and Sorenson experimented with a closed-air, solar-cooking system for drying peanuts *(63)*. The system uses a conventional absorption refrigeration unit powered by a solar collector. Air leaving the drying peanuts passes over evaporative coils to remove moisture, then to the condenser unit to be reheated before being passed back through the peanuts. This system features a closed-air cycle with minimum energy losses to ambient air which makes it an energy efficient drying system. However, information on the comparative costs of the system for drying peanuts and other agricultural crops is not yet available.

The short peanut-curing season requires that other uses be found for the system. A thorough economic assessment of multiple-use systems, which combine peanut curing with other crop drying and/or space heating applications, is needed.

Tobacco Curing. Tobacco curing is another highly energy intensive farm activity. Among crops dried, tobacco is second to corn in the total quantity of fuel used. According to estimates by the Council for Agricultural Science and Technology, tobacco curing requires 32 trillion Btu of energy each year *(16)*.

The two principal types of tobacco, flue-cured and burley, account for over 90 percent of the U.S. tobacco acreage. Nearly all of the fuel used in tobacco curing is for flue-cured tobacco. Burley tobacco is cured with natural air, normally without added heat. The curing process for flue-cured tobacco involves the gradual drying of fresh leaves over a period of 5 to 7 days under controlled conditions of temperature, moisture, and air supply. In conventional curing systems, temperatures as high as 170°F are reached during the latter stages of curing.

Solar energy systems for tobacco curing are being studied at several locations. Johnson, at North Carolina State University, developed a three-chambered, bulk-curing barn which combined solar energy and heat recycling to achieve high thermal efficiency *(48)*. Tests in 1978 and 1979 indicated fuel savings of up to 70 percent compared with conventional bulk-curing barns. Staggered loading of the three curing chambers permitted improved solar energy use and eliminated the need for thermal storage. Data on costs of the system are not available.

Huang and Toksoy, also at North Carolina State University, developed a greenhouse solar energy system designed for year-round use to cure tobacco and peanuts, produce horticultural crops, and grow tobacco plants for fully automated transplanting *(44)*. A metal framework was placed inside the greenhouse to hold the bulk-curing racks. The framework was then enclosed with black, heat-absorbing panels. Full-scale tests of the system showed fuel savings of 43 to 54 percent compared with a conventional bulk-curing barn. According to its developers, the costs of the greenhouse/bulk-curing barn are about the same as a conventional, commercially manufactured bulk-curing barn. Thus, the 43- to 54-percent fuel savings would represent a net decline in curing costs.

Cundiff developed a tobacco-curing system for use with a multipurpose solar-drying shed, the same as used by Butler and Troeger for peanut curing at Tifton, Ga. *(17)*. The shed was designed for three principal crops in sequence: tobacco in July and August, corn in August and September, and peanuts in September and October. Tobacco was cured in mobile-style, bulk-curing barns alongside the drying shed. All air was drawn into the barns from the rock storage structure to cure the tobacco. In 12 tests, the solar system supplied one-third of the total heat energy input required. Cost data of the system are not yet available.

Henson and others at the University of Kentucky tested several solar-augmented systems for curing burley tobacco *(37)*. These included: (1) solar field curing of stalk-cut burley followed by conventional barn curing, (2) solar field curing of stalk-cut burley followed by solar barn curing with rock storage, and (3) leaf curing in a prototype solar bulk-curing barn with rock storage. These tests indicated that, under present price relationships, a solar collector and rockbed storage system cannot economically compete with fossil fuel systems in only curing stalk-cut or bulk-cured burley tobacco. The Kentucky researchers, like most other solar energy scientists, concluded that multiple-use solar energy systems are necessary.

Fruit and Vegetable Drying

Economical solar food dryers are available for small drying systems. Costs range from $20 to $40. These low-cost dryers may be used to dehydrate a large variety of fruits and vegetables. Fruit is usually dried to 15- to 20-percent moisture, and vegetables to 5 percent of their original moisture content.

One food dryer built by families cooperating in the Small Farm Energy Project in Nebraska is made primarily of 1/2-inch plywood with 2 x 2's as the framing structure *(78)*. Outside dimensions of the dryers are 2 ft by 4 ft or 2 ft by 6 ft. Ventilation holes at the front and back of the dryer are covered with mosquito netting or window screen. Nylon or fiberglass screen is used for the food trays. Wooden dowels support the screen on the collector frame. The interior of the box is painted black to improve heat absorption.

This dryer can be used alone or with a solar window box collector. A small 10-ft^2 window box collector, costing about $50, improves the efficiency of the solar dryer especially during the fall months.

Both the solar dryer and collector can be used in the early spring as a cold frame. In the winter, the window box solar collector can be attached to a window of the farm house. This food dehydrating system is described by the Nebraska Extension Service as a "high quality" method of preserving produce from the farm garden or orchard.

Another low-cost solar food dryer, incorporating a concentrating reflector, has been built by Coleman at the U.S. Citrus and Subtropical Products Laboratory, Winterhaven, Fla. *(13)*. The unique feature of this dryer is a low-cost focusing surface that concentrates the sun's radiation just enough to dry foods but not enough to cause them to overheat or burn. The curved focusing surface is made of ordinary household aluminum drawn over strings held taut by a framework of laminated wood curves or parabolas. The drying surface, 5.3 ft^2, is covered with 4-mil polyethylene.[9] This dryer, costing about $20, has successfully dried sliced peaches, mangoes, peppers, onions, plantains, and beef. The research program that developed this dryer is also engaged in developing modular systems which can be used on a larger scale for commercial applications.

Animal Shelter Heating and Ventilating

Efficient solar units, designed for space heating and cooling livestock shelters, are yielding at least a 5-year payback. These solar collectors often receive enough use that multipurpose considerations are not necessary to make them economical.

Livestock confinement enterprises require fresh air to maintain acceptable levels of moisture, dust, odor, and toxic gases. They also may require large amounts of low-temperature energy to maintain comfortable and healthy environments, especially in

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[9]Plans for this solar dryer are available from the U.S. Citrus and Subtropical Products Laboratory, P.O. Box 1909, Winterhaven, Fla. 33880.

buildings housing young animals that produce little metabolic heat. Air drawn through solar collectors is ideal for conditioning livestock enclosures because the process reduces humidity.

Space heating for livestock and caged layers has not been as common, or as necessary, as space-heating requirements for poultry brooding. Livestock require less than one-fourth the amount of energy used annually for poultry brooding in the United States. Nevertheless, as confined livestock and layer systems become more popular, the demand for air-conditioning systems will increase.[10]

Solar demonstration livestock farm projects are ongoing in nine States, including nearly 90 farms. A promising solar energy system is being demonstrated on each farm. These systems, incorporating various combinations of designs and uses, include swine nurseries, swine farrowing, dairy parlor space heating, dairy hot water, hot water for feedmill-turkey operations, heat for turkey brooding, and calf and veal barn space heating. About one-half of the solar projects involve solar-heated swine facilities, indicating that solar energy may be an appropriate and economical technology for farrowing and nursery buildings. Estimates made in the late seventies indicated a 6- to 10-year payback for solar-heating swine systems. By 1980, the length of payback had been shortened by rising fuel prices and the use of solar collectors to both cool and heat buildings. Some researchers suggest that the benefits from summertime cooling are greater than those gained from wintertime space heating. Considering both heating and cooling values, the current payback for these systems is about 5 years.

One economical system, the Spillman wall, was developed at Kansas State University *(83)*. The main working part of this system is a massive, vertical, south-facing, concrete block wall parallel to and 16 inches in front of the existing south wall of the swine building. Concrete blocks are stacked without the use of mortar so that ventilation air can be moved by fan through the wall. The wall, painted black on the outside, serves as a collecting surface

[10]The term "air-conditioning" means both space heating and cooling.

and as an energy storage medium, providing a time lag between collection and delivery of solar energy and reducing the wide temperature fluctuations from daytime to nighttime. This, in effect, saves fuel and results in a more constant temperature throughout the 24-hour day than could otherwise be maintained. A double transparent cover is constructed on the outside of the concrete block wall. The air moving between these two layers of plastic in the daytime picks up heat which is, in turn, deposited in the concrete blocks.

This solar collection system is intended as a supplement to a conventional heating system, not as a replacement. Results of this promising experiment showed that an equivalent of 1 to 2 gallons of LP gas can be saved for each square foot of collector surface when heat is required. The Kansas research showed that this solar collection system was competitive with electricity without considering the supplemental tax credits that are available. With tax credits, this system was competitive with propane at 1978 prices.

The economic analysis performed on the Spillman wall also did not consider the advantages of using the system over longer periods to moderate temperature extremes in spring and fall, for summer cooling, or for alternate uses such as grain drying in the fall. (In the summertime, cool air can be moved into the wall at night for daytime cooling.) When all possibilities are taken into account, this system appears to be economically feasible over much of the Corn Belt, where a large percentage of the U.S. swine herd is raised. Since 1978, the wall-type solar collector for heating and ventilating swine-farrowing houses has been gaining popularity in the eastern Great Plains and Midwest.[11]

Another promising solar swine unit is a modified-open-front swine-farrowing building designed by Schulte *(74)*. Solar collectors are used to heat the rear one-third of a 20-foot deep house in the daytime and to store heat for the entire building at night.

[11]Plans are available from the Dept. of Agricultural Engineering, Kansas State Univ., Manhattan, Kans. 66506. The price of a set of plans at the time this report was prepared was $3.

The front two-thirds, having a southern exposure, is heated passively in the daytime. This collection system, including the passive windows, the solar collector, and the heat storage medium, could be constructed for $6,429 (1979 dollars), or about a 15-percent increase over the cost of a similar hog house having no solar components. Schulte concluded that the supplemental solar heat resulted in an estimated 1-percent improvement in feed efficiency as well as energy savings which make it possible to recover initial investment costs in 10 years, not considering tax credits.

A vertical solar wall collector used to preheat ventilation air for two 25-sow farrowing units in Nebraska also had an estimated payback of about 10 years. Payback for these single-purpose agricultural structures is below 10 years when regular investment credit and business energy tax credits are taken.

In Illinois, a system was designed which can be used all year on both farrowing houses and nurseries *(43)*. This system, now commercially available, features a liquid-type, flat-plate collector that is roof-mounted. The 480-ft^2 collector provides both heat and hot water and has been estimated to have a payback of less than 5 years.

By 1980, several manufacturers were advertising solar energy systems. Some manufacturers were producing solar panels that could be added to existing swine houses. Others integrated solar panels into the roof structure of new buildings. The payback of commercial liquid-type collectors designed for ventilation purposes is not as rapid as for the home-built, air-type systems. However, the payback of commercial air-type collectors that are structural components of roofs may be as little as 1 year.

Solar collectors for supplying energy to swine enterprises appear to be economical, and, considering their capacity for cooling as well as space heating, they have wide geographic potential. Multiple uses are less important for swine needs than for crop drying and curing because the solar collection system can be used over a longer period of time. Where possible, however, costs can be reduced by multiple uses. Drying grain is one alternative use on grain-hog farms as long as farmstead layout is conducive to both uses. The solar technologies that are most promising for confined swine systems are those that are low in initial cost, simple to construct, easily maintained, and manageable. The rate of adoption should increase as farmers learn about systems having paybacks of 5 years or less.

Hot Water for Milking Parlors

Dairy farms require large amounts of energy for heating water twice a day throughout the year.[12] An equivalent of 23.4 trillion Btu of energy is used annually in milking activities in the United States *(29)*. Of this total, water heating requires 35 percent; milk cooling, 26 percent; milking, 22 percent; space heating and ventilating, 9 percent; and lighting, 7 percent.

Rising energy costs may cause many dairy farmers to consider opportunities for energy concentration, particularly alternate energy sources for heating water. Stephenson reports that if presently known energy-saving techniques were used by Vermont dairy farmers, energy use could be reduced by 30 percent *(85)*. The two alternative energy sources receiving greatest attention throughout the United States are solar collectors and waste heat recovery systems (heat exchangers). Most studies indicate that, for dairies having 40 cows or more, heat exchangers save more energy and have a faster payback than solar water heaters. For dairies with fewer cows, solar collectors may be more economical than heat exchangers.

As part of a coordinated research program on solar energy's waste heat recovery and energy conservation, USDA dairy

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[12]Heated water is used mostly for cow preparation and sanitation. For cow preparation, water heated to 95 or 110°F is adequate. Automatic cow preparation systems require an average of about 2 gallons of warm water per cow per wash. Manual systems require only about one-half gallon of water per cow per wash. For sanitation—washing pipelines and bulk tanks—water must be heated to 160°F or warmer. (If disinfectant chemicals are added to the water, temperatures of 135°F are sufficient.) Short pipelines use about 100 gallons of hot water. Bulk tanks require about 50 gallons of hot water per wash.

researchers at Beltsville, Md., have developed a solar energy system to supply hot water for a 200-cow milking parlor *(89)*. The main components of the system are a 1,000-ft^2 single-glazed, flat-plate collector and a 4,000-gallon insulated fiberglass holding tank for the hot water generated by the collector. A heat exchanger is used to recover waste heat from the milk refrigeration process and to heat water.

The economic feasibility of solar energy for a 200-cow dairy farm was evaluated using the SOLCOST economic analysis program *(82)*. The system was modeled with and without waste heat recovery, assuming either oil or electricity as the backup fuel for water heating at several U.S. locations. Some of the more important parameters used in this analysis were: life of system, 15 years; discount rate, 11 percent; loan terms: 5 years, 20 percent down, 14 percent interest; fuel inflation rate, 14 percent; general inflation rate, 10 percent; maintenance cost, 0.5 percent; and collector cost, \$12/ft^2.[13]

According to the Beltsville study, the solar collector requirements for the middle United States are about twice those of extreme southern locations and half those of cold ones. For example, the amount of flat-plate collector needed to produce 1 Btu per day is 0.0015 ft^2 in central locations, 0.008 ft^2 in southern areas, and 0.0045 ft^2 in northern areas. (These coefficients will vary with the type of materials used to construct solar panels and the efficiency of the collector.)

Payback for the Beltsville solar collector ranged from 5.4 to 9.9 years (table 7). Cost of the system varied by geographic location, by the type of fuel being replaced, and by whether waste heat recovery was a part of the system. The relative costs of solar energy versus waste heat recovery were not considered in the analysis.

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[13]Parameters used in this and other research reviewed in this study reflect economic conditions at the time of the research cited, not conditions at the date of this publication.

Table 7—Economics of solar energy systems for 200-cow dairy farms at selected locations, using the SOLCOST economic analysis program, 1979

Geographic area of the United States[1]	Waste heat recovery	Fuel used	Optimum collector size	Payback period	Net present worth of solar system	Percentage of annual energy load provided by solar system
			Ft²	*Years*	*Dollars*	*Percent*
North	Yes	Oil	210	9.7	- 1,198	15.6
	Yes	Electric	410	8.1	361	26.1
	No	Oil	610	7.6	1,494	32.8
	No	Electric	810	6.7	5,523	40.2
Central	Yes	Oil	210	9.9	- 1,317	21.4
	Yes	Electric	210	8.6	- 284	21.4
	No	Oil	610	7.5	1,175	41.8
	No	Electric	810	6.7	5,267	49.4
Southwest	Yes	Oil	310	8.0	450	76.7
	Yes	Electric	310	6.8	2,341	76.7
	No	Oil	754	6.3	6,575	90.5
	No	Electric	754	5.4	11,857	90.5

[1]Areas based on climatic data as follows: North (Madison, Wis.); Central (Washington, D.C.); and Southwest (Los Angeles, Calif.).

Source: *(89)*.

Stipanuk and others at Cornell University simulated solar water-heating systems for dairies at 10 locations using the F-CHART simulation program developed at the University of Wisconsin (table 8) *(87)*. The cities selected for the simulation geographically represent the major U.S. dairying areas. Some of the more important parameters used in the simulation were: period covered, 20 years; discount rate, 10 percent; loan terms: 10 years, 10 percent interest, no down payment; fuel price inflation rate, 11 percent; maintenance and insurance cost, 1 percent per year; inflation rate, 9 percent; and collector cost, $26.20/ft^2.

Table 8—Solar water-heating system costs and savings, 100-cow dairy farm[1]

Location	Solar fraction[2]	Collector area	Solar system cost	Present worth of solar savings (20-year lifetime)
	Percent	*Ft²*	*Dollars*	
Riverside, Calif.	72.5	160	4,692	7,237
Dallas, Tex.	71.7	220	6,264	5,816
Columbia, Mo.	75.2	300	8,360	4,607
Des Moines, Iowa	77.3	320	8,884	4,497
Lansing, Mich.	74.5	360	9,932	3,194
Madison, Wis.	74.7	380	10,456	2,790
Harrisburg, Pa.	73.7	380	10,456	2,638
Rochester, Minn.	70.5	360	9,932	2,584
Ithaca, N.Y.	71.8	400	10,980	1,921
Columbus, Ohio	70.6	400	10.980	1,736

[1]Excludes installation labor.
[2]Solar fractions assumed in this study are higher than what the dairy equipment industry advertises for their solar hot water systems.

Source: *(87)*.

The present worth of the solar energy systems varied from a low of $1,736 at Columbus, Ohio, to a high of $7,237 at Riverside, Calif. According to the Cornell study, the economics of solar water heating look much better in the southwestern part of the Nation than in the midwestern and eastern sections.

The solar energy systems' values were compared to a heat recovery system supplying an equal share (approximately 74 percent) of the water-heating load. The present worth of energy savings over the 20-year life of the heat recovery system was estimated at $12,676. The installed cost of the system was $2,100. Thus, the Cornell study concluded that heat recovery systems offer a much more attractive investment opportunity than solar energy systems.

Wiersma and others at the University of Arizona also compared the use of solar energy to waste heat recovery and energy conservation *(116)*. A major conclusion of their research was that solar energy could not compete economically with the recovery of waste heat from the milk refrigeration system. According to project leader Wiersma *(115)*:

> "Solar energy represents another alternative source from which water can be quite readily heated. The technology is available for water heating and a dairy is generally compatible with solar collector systems. However, the less expensive low technology systems have temperature limitations similar to those of energy recovery systems. Other disadvantages include: relative complexity of installation, large storage requirement, variations in capacity with season weather, and high maintenance requirement. In general, there appears to be little, if any, economic justification for the installation of a solar water heating system on dairy farms when refrigeration systems waste-heat is available."

Elwell and others studied an integrated commercial system that used solar energy, waste heat recovery, and off-peak electricity to supply water-heating needs for a 110-cow Ohio dairy *(22)*. This system consisted of a bank of high technology vacuum-insulated tubes with an effective collector area of 27 ft^2. A vacuum tube-type collector was selected because of the need for 160°F sanitation water. The system was designed to provide up to 50 percent of the hot water needs under ideal weather conditions. Off-peak electricity was used as backup during cloudy weather.

Preliminary conclusions of the Ohio study suggest annual cost savings from the solar collector of around $1,000. With the high investment cost of this type collector system and the current price of electricity, a payback time well beyond 20 years is projected, excluding tax credits. However, the manufacturer of the system used in this study foresees mass production reducing collector costs substantially. Mass production, available tax credits, and rising electricity rates may make the system feasible.

Several commercial dairy producers have installed solar water-heating systems. Hill reports that a California dairyman achieved a payback of 6 to 7 years, excluding tax credits, when replacing an electrically heated hot water system *(41)*. Experience in Vermont has been somewhat different, where about two-thirds as much insolation has hampered solar demonstration projects *(57)*.

The future of solar hot water systems for dairies is uncertain. Waste heat recovery systems may, in most instances, be the most economical choice for farmers. With proper selection of equipment, heat exchangers can provide at least 75 percent of the hot water requirements for dairies *(55)*.

Poultry House Heating

The payback for solar collectors used to space heat caged layer houses is under 5 years. However, for brooder houses, where heat requirements are high for only short periods of time, researchers have, thus far, been unable to design economical solar collection systems.

The energy used in poultry production in 1980 amounted to 41.1 trillion Btu or the energy equivalent of some 447 million gallons of LP gas (estimate adjusted to 1980 levels) *(89)*. Over 70 percent of this amount was used in brooding young chicks. Supplemental heat is extremely critical for the first 2 or 3 weeks of a chick's life. The poultry industry depends on fossil fuels to supply this heat, and industry leaders have been quick to recognize that poultry producers are especially vulnerable to energy interruptions or shortages and rising costs. For this reason, there is widespread interest and progress in developing alternate energy sources for poultry brooding.

Scientists at USDA's South Central Poultry Research Laboratory designed and tested several solar-heating systems for broiler houses *(64)*. Each of these systems was designed to be used with advanced energy conservation techniques. Energy conservation research had already demonstrated that proper insulation, precision ventilation control, reduced brooding temperature, and limited-area brooding could reduce winter fuel requirements by 70 percent. The solar energy systems supplied up to 75 percent of the remaining heat requirements under winter conditions and essentially all of the heat required at other times.

Several advantages exist for a hot air collector and rock storage system compared to a system using water as the collection and storage medium. The hot air system was more efficient (collecting 57 percent of available insolation compared with 40 percent). It eliminated freezing problems, was easier to operate, and, being simpler, was less costly to build.

Reece calculated the operating cost of a solar energy system at about $41 per day for a 20,000-bird broiler house *(64)*. The cost of a conventional LP gas system for the same house was estimated at only $6.56 per day, assuming LP gas at 60 cents per gallon. According to Reece, the price of LP gas would need to reach $3.25 per gallon for the solar-heating system to approach economic feasibility.

University of Maryland researchers compared heating costs for broilers during 1978 and 1979, using three different heating methods *(11, 25)*: (1) conventional whole-house brooding with

LP gas heat, (2) partial-house brooding with LP gas heat, and (3) partial-house brooding with solar heat and rock storage backed by LP gas. Heating costs per 1,000 broilers for the three methods were \$26.01, \$13.54, and \$54.43, respectively. Little use of the relatively high-cost solar energy system was largely responsible for the sizable cost differences. Because of their special heating needs, only 21 percent of the heat theoretically available was actually used to heat broilers. If as much as 75 percent of the deliverable heat could be used in broiler production, the heating cost for the solar system would drop from \$54.43 to \$19.62 per 1,000 birds. Considering the rapidly rising prices and potential scarcity of conventional fuels, this would make the solar alternative substantially more attractive.

Rokeby and Redfern found solar heating to be uneconomical *(69)*. Their study was based on an 8,000-bird broiler house with a 2,000-ft^2 flat-plate collector to supply heated ventilating air. The house was constructed with ceiling and sidewall insulation and half-house brooding was used for the first 3 weeks. It was scaled up to a 16,000-bird house with a 4,000-ft^2 collector for the economic analysis. The total investment cost of the solar-heating system was estimated at \$55,500, or about \$14/ft^2 of collector area. The system supplied 52 percent of the heat during the fall-winter-spring season and resulted in annual net savings of \$316. The estimated annual cost of the system was \$5,689. To be economically feasible, the initial investment cost would have to drop from \$55,500 to \$5,500, or the price of LP gas would need to rise from 40 cents a gallon to \$2.19 a gallon.

Hartman and Robertson are working with both passive and active solar energy systems for broiler house heating *(33, 67)*. Their objective is to develop low-cost systems which farmers can build with locally available materials. The passive system comprises a south-facing hillside below a 25,000-bird commercial broiler house for the collector site. A 6-inch-deep rockbed, painted flat black, serves as the collector, heat storage medium, and heat exchanger. Ambient air moves by convection through the rockbed into the broiler house. During a test brooding period in late fall, 60 percent of the heat requirement of the broiler house was supplied by the passive solar collector. Extensive testing has revealed a number of problems with their active system which is being modified to improve system efficiency and extend expected life.

USDA engineers at the Southeast Poultry Research Labaoratory, Athens, Ga., constructed two identical controlled-environment broiler houses for solar-heating studies *(20)*. In trials using partial-house brooding, 65 percent of the required heat was supplied by the sun. Of three methods used to deliver solar heat to the brooding area—heated floor, fin tube convectors, and heated ventilating air—the heated ventilating air system proved most effective. Studies are continuing to determine functional requirements of different components and establish design criteria for practical solar brooding systems.

Forbes and others modified a pre-engineered metal building to incorporate a simple, homemade solar air heater as an integral part of the south wall *(27, 28)*. Rock heat storage was provided in an insulated chamber under the floor of the building. The system performed well under test conditions. The most attractive feature of this building design was the low cost (84 cents/ft^2) of materials for the solar collector. This system appears to be economical, although it needs further evaluation.

Auburn University researchers studied five alternate methods of transferring solar heat to the broiler brooding area *(26)*: (1) heated concrete slab brooding floors, (2) whole-room heating by fin tube convectors, (3) hovers heated by fin tube convectors with natural convection, (4) hovers heated by fin tube convectors with forced air, and (5) heated ventilation air. Hovers heated by fin tube convectors with natural convection and heated ventilation air showed the most promise, proving technically feasible, but in each case, a backup system was needed to increase constant heat for young chicks.

The Auburn researchers also studied the time distribution of brooding heat requirements for broilers. Heat requirements during the first quarter of the year were approximately 12 times as large as that during the third quarter. No heat was required after the fourth week at the research site. The Auburn researchers concluded that a solar space-heating system could not be utilized efficiently because of the wide variations in heat requirements for brooding chicks. Problems with wide variations in heat demand for brooders are similar to those of providing solar space heat for residences—a high fixed cost device sitting idle much of the year. The Auburn researchers are considering a low-cost, sidewall air collector to supply nonpeak heating demands, and alternate energy sources, such as wood or other biomass, to supply heat during peak demands. They also are studying alternate broiler management practices, such as multistage brooding, which will help even out energy demand over time and more fully draw on the solar-heating system.[14] Researchers at Auburn and elsewhere will eventually determine the most economical combination of solar and conventional space-heating systems.

In a 1977 simulation study, Auburn researchers concluded that solar energy would not be competitive with LP gas until the price of LP gas reached 85 cents a gallon (versus 36 cents a gallon in 1977 *(114)*). The study compared costs of three broiler management systems, conventional whole-house brooding, partial-house brooding, and multistage brooding, using LP gas and solar heat. Fuel savings, compared with conventional whole-house brooding systems using LP gas, were: partial-house brooding with LP gas, 55 percent; partial-house brooding with solar, 75 percent; multistage brooding with LP gas, 55 percent; and multistage brooding with solar, 80 percent.

Carpenter and others described a demonstration solar energy system designed to preheat ventilation air for a turkey brooder house in southwestern Missouri *(12)*. The house was used to brood 7,000 to 10,000 turkey poults in 7-week cycles. (After the 7-week brooding period, the poults were moved to an intermediate grow-out house and finally to a finishing house.) The researchers concluded that a special brooder house permits

[14]In multistage brooding, a new batch of chicks would be started in the same solar-heated brooding chamber every 3 or 4 weeks, or starts could be staggered in adjacent houses served by the same solar-heating system.

more efficient use of solar heat than a conventional broiler-brooding system where the complete grow-out cycle occurs in the same house. The demonstration solar system consisted of a 2,000-ft^2 air collector and enough rock to store the heat collected on a clear December day. During a 29-day test period in November and December, savings of LP gas averaged about 20 gallons per day. Assuming similar fuel savings for a 5-month heating season and an LP gas price of 65 cents per gallon, this translated into an annual savings of about $1,950. Total cost of the system was $8,661 for an average cost of $4.33/ft^2 of collector.

Hietala and others cited investment cost as the most important factor determining economic viability of solar systems for turkey production *(39)*. They determined that air systems costing below $7/ft^2 of collector area were economically practicable. Systems in this price range are used on some Minnesota farms.

Hall and others used solar energy to help improve the feed efficiency of a layer flock *(31)*.[15] The solar unit consisted of a 974-ft^2 solar air collector and was designed to provide supplemental heat for ventilation air to a 5,000-bird, cage layer house in East Lansing, Mich. The collector was built in 1976 for approximately $2.77/ft^2, or a total cost of $2,700. The estimated feed saving was $650 per year; payback was estimated at about 4 years. According to the study, other advantages of the system included drier fecal matter, fewer undesirable odors, and better control of flies.

A substantial amount of energy can be saved in poultry production through solar energy systems. A well-designed system used with practical energy conservation measures can supply up to 75 percent of the energy required for poultry brooding in winter and an even higher share at other times. However, few economical systems have been reported for brooding systems.

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[15]Within certain limits, the higher the temperature in a poultry laying house, the higher the feed efficiency or the lower the feed requirements per dozen eggs. Feed efficiency increases approximately 1 percent for each 2°F increase in temperature *(88)*.

A major barrier to developing solar energy systems for poultry brooding is still the relatively high capital cost per unit of energy collected and used. Future acceptance of solar energy as a viable alternative to fossil fuels can be enhanced by:

- Finding alternate uses for the overflow energy.
- Adopting a brooding system that will use the solar system more during the year, such as multistage brooding.
- Modifying the solar system to reduce fixed cost and/or improve efficiency.
- Determining the optimum fraction of total heat requirements supplied by the solar collector.
- Finding other uses for solar heat when not needed for warming young chicks—a multiple-use collector.

Greenhouse Heating

For most existing greenhouses, conservation measures still offer the greatest economic savings. However, a few newly constructed commercial greenhouse firms are installing solar collector systems.

The greenhouse industry is the most energy intensive segment of agricultural production, and is critically dependent upon a reliable energy supply. The approximately 9,000 acres of U.S. commercial greenhouse production of florist, nursery, and vegetable crops requires the energy equivalent of nearly 600 million gallons of LP gas annually for heating. Also, an increasing number of full-time and part-time farmers are adding greenhouses to their farmsteads, both for providing home space heat and for growing vegetables.

Loss of heat at a crucial time can result in a complete crop loss in the commercial greenhouse industry. The uncertainty of fuel supplies coupled with rapidly rising prices has focused attention on alternate energy sources. Substantial effort is being directed at developing solar energy systems to supply part of the energy requirements of the commercial greenhouse industry and to design practical small-sized greenhouses for home use.

When sunshine is available, greenhouses serve as good solar collectors. On sunny days, little supplemental heat is required even during cold weather. However, greenhouse structures are notorious for their rapid loss of heat at night and during cold weather.

Effective greenhouse insulation is essential if solar energy is to make an economic contribution to greenhouse energy requirements. Consequently, much of the research on greenhouse solar energy system design has been combined with research on energy conservation.

Researchers at Cornell University are basing their solar energy work on the economic axiom that it is feasible to consider installing a solar energy system only when the marginal cost of solar energy is less than the marginal cost of energy conservation—an economical principle that should guide all energy R&D *(3)*. They have concluded that, up to a fairly high level, energy conservation is less expensive per unit of fossil fuel saved than the cost of energy from either a passive or an active solar energy system. The central feature of the Cornell solar greenhouse heating system is a multilayer night blanket insulating system which reduces night heating requirements by 80 percent. The addition of a passive solar energy collection and storage system reduces night heating needs an additional 10 percent. The total present value of the night blanket-solar energy system, based on a life cycle cost-benefit analysis, was $7.68/ft^2 compared with an installed cost of $2.25/ft^2.

Rotz and others at Pennsylvania State University evaluated the energy savings potential of a number of solar energy and thermal insulating systems separately and in combination *(71)*. The system providing the greatest fossil fuel savings was the combination of a heavy thermal insulating blanket and an external solar collector system. When used with either an acrylic- or polyethylene-covered greenhouse, fossil fuel savings ranged around 90 percent of the amount required by a conventional glass greenhouse. The system that showed the least potential for fuel savings was an internal collector system used to collect excess solar heat within the greenhouse.

Rotz and Heins developed comparative cost-benefit data of owning and operating various greenhouse heating and fuel conservation systems over a 10-year cycle *(72)*. Total savings for each system were calculated using the conventional glass greenhouse with gas boiler and fin tube heat as the basis of comparison. Of the 11 systems studied, a greenhouse heated with a flat-plate solar collector was least attractive; it reduced operating costs, but the high initial cost caused a relatively long payback of 14.6 years. Payback for the other 10 energy conservation systems ranged from less than 1 year to just 3.1 years.

In a third study, Rotz compared cost benefits of six different greenhouse energy conservation systems at eight locations across the United States *(70)*. Again, savings calculated by using a conventional system resulted in zero or negative savings in each location except Denver, Colo., where savings of 14 percent were generated. The double-acrylic cover and nighttime thermal blanket insulation system generated the highest savings at most of the locations. When a flat-plate collector was added to this system, savings dropped in each of the locations except Denver.

Rutgers University has emphasized development of a low initial-cost system *(58, 77)*. The system has four essential components: a low-cost, external plastic solar collector; a movable curtain insulation system; an underfloor storage tank capped with porous concrete which serves as the greenhouse floor; and vertical, plastic curtain heat exchangers. A fossil fuel unit provides backup heat. Estimated fuel savings with the complete system amounted to 40 cents/ft^2 of greenhouse floor area. Labor and materials for the complete system initially cost about \$4.60/ft^2 of floor area, based on a complete retrofit situation, where the conventional heating system, floor, and benches are replaced. The study concluded that this would not be economical under current fuel prices. However, new greenhouse construction may enhance the feasibility of the system, where savings on the conventional heating system, floor, and benches can be applied to construction of the solar heating system. The Rutgers solar system was adopted by some commercial greenhouse firms in the Northeast in 1980.

Akridge, at Georgia Tech, is also placing emphasis on a low initial-cost system which combines the collection and storage functions into one unit *(2)*. The system uses a single-glazed rock bed, painted flat black, which collects, stores, and exchanges the heat. Varying degrees of sophistication can be built into the system from simple, passive designs located on hillsides and costing under $1/ft^2 of collector area to more complicated automatically controlled systems costing under $2/ft^2. The system's performance has been very promising. (A similar rock heat storage system constructed and studied at the U.S. Grain Marketing Research Laboratory, Manhattan, Kans., did not prove economical for grain drying.)

The Lockheed-Huntsville Research and Engineering Center at Huntsville, Ala., under a DOE contract, designed and installed a solar energy system to heat a commercial greenhouse in Springfield, Ohio *(84)*. The system provided 60 percent of the heat requirements of an 8,650-ft^2 commercial greenhouse. It consisted of a 6,000-ft^2 flat-plate water collector with 25,000 gallons of storage, costing $65,000 or $10.83/ft^2 installed. The cost of the solar energy supplied by the system was about $28/million Btu, much more expensive than conventional energy sources.

Research at Ohio State and Purdue Universities emphasized longer term solar energy storage. Ohio State researchers used a solar pond with saline gradients to collect and store excess solar heat in summer for winter use *(75)*. The pond was capable of attaining and holding temperatures up to 175°F even with winter ice on the surface. The Ohio State researchers also experimented with a polystyrene-bead nighttime insulation system which was projected to reduce nighttime energy requirements by 80 to 90 percent. Analysts postulated that the solar pond could supply the remaining energy requirements. However, the economic feasibility, as in so many solar studies, was not determined.

Dale and others at Purdue University studied the use of soil and ground water underneath a greenhouse for heat storage *(18)*. Their collector unit was designed with reflectors at the top and bottom to increase the efficiency of the unit. While the system looks promising, no economic evaluation has been made.

Texas A&M researchers, using another approach, are working on a unique fluid roof solar greenhouse *(113)*. The fluid roof serves as an infrared filter which admits the photosynthetically active part of the solar radiation and excludes the remainder by converting it to heat and storing it for nighttime use. Reported advantages of the system include reduced heating and cooling requirements and improved conditions for plant growth. However, no payback data exist.

Another phase of the greenhouse solar energy research is directed at developing solar energy systems for greenhouse/residence combinations. The advantage of the greenhouse/residence combination is that excess heat from the greenhouse during winter months can be used to heat the residence, resulting in a substantial saving in fossil fuel. At the same time, the combination provides a potential for year-round vegetable production and, for many people, enhances the quality of the home environment. However, unless carefully designed, attached greenhouses may require more energy than they produce. Work on greenhouse/residence combinations is being emphasized at Clemson University, Clemson, S.C., Colorado State University, Fort Collins, and the University of Arizona, Tucson.

Clemson scientists designed and built four greenhouse/residence prototypes for which added heat was supplied by separate flat-plate collectors *(23)*. This research program was aimed at making the residence more self-sufficient in energy and food. It also provided for some recycling of domestic wastes. Preliminary data indicate that the value of vegetables produced for home use may cover operating expenses but not investment costs.

University of Colorado scientists concluded that constructing solar energy systems large enough to compensate for the high heat loss of greenhouses is not economical *(79)*. To improve the performance of their solar-heated greenhouse/residence combination, they are placing nighttime-insulated covers under the greenhouse roof, reducing greenhouse temperature, and solar heating both the growing medium and irrigation water. The insulated cover and reduced greenhouse temperature decreased heat requirements for the greenhouse by 35 percent.

The competitiveness of solar energy improves substantially in the Desert Southwest where more solar energy is available, and less is needed for greenhouse/residence combinations. University of Arizona scientists designed a unique and innovative Clear View solar collector *(91)*. This collector consists of Venetian blinds that are coated on one side with a dark absorptive paint and on the other with a reflective paint. They are encased in the air space between two double-panes of window glass, and can be adjusted to obtain maximum absorption or reflection of the sun's heat while remaining in a vertical attitude. Air heated by the blinds can be passed through the house or on to rock storage for night use. This type of collector, which has been installed in several Tucson area homes, has several advantages for use in solar-heated residences: placement in a vertical wall, service as a window or just part of the wall, adjustment to absorb or reflect heat capability to close at night to help conserve heat, and adaptability to heating either air or water. It is also attractive. According to Thompson and others at the University of Arizona, a Clear View solar collector and an attached greenhouse both are competitive with conventional energy sources in the Southwest (figs. 3 and 4). Both systems were less costly than electrical resistance heat and heat pumps. However, this type of collector has not been thoroughly tested in other regions of the country.

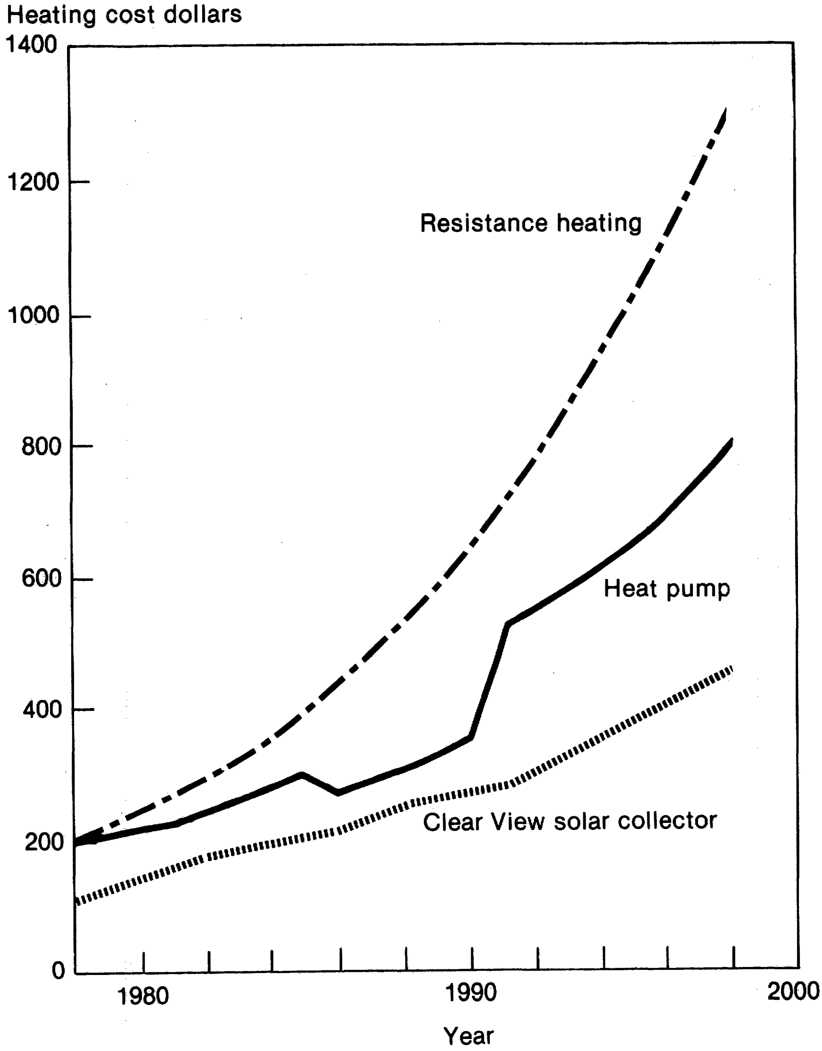
Irrigation

Solar-powered irrigation pump technology is still in the developmental stage. However, photovoltaic systems appear most promising.

Irrigated agriculture is highly energy intensive, especially in areas where agricultural production is dependent on deep-well pumped water for irrigating crops. Farmers depending on underground aquifers for irrigation water are concerned about short supplies of water and energy. For example, deep-well pumping is prevalent in Arizona where 99 percent of all cropland is irrigated. The average lift is 350 feet, and the cost of energy for pumping this irrigation water is becoming prohibitive *(1)*.

Figure 3

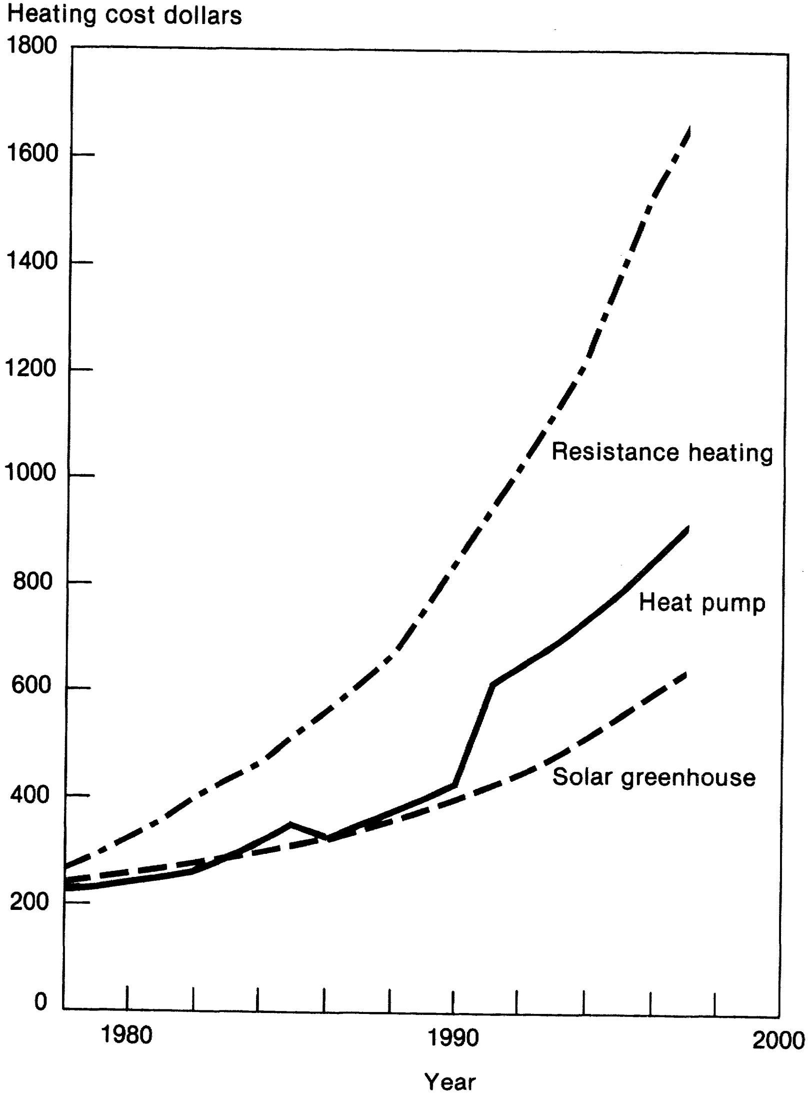
Economic Comparison of Clear View Collector Heating with Other Methods



Source: (91).

Figure 4

Economic Comparison of Solar Greenhouse Heating with Other Methods



Source: (91).

Irrigation pumps may be powered by either of two solar technologies—direct solar thermal energy or photovoltaics. Batteries are used for energy storage in the photovoltaic system, giving it 24-hour capacity. The need for an economical battery storage system has slowed the development of photovoltaic systems. To help solve this problem, an extensive battery-testing program has been initiated by Sandia National Laboratories, Albuquerque, N. Mex., where promising new storage batteries include Rodox and zinc bromine flow systems.

A direct solar thermal irrigation system may use a concentrating or a nonconcentrating solar collector. A nonconcentrating collector may be a solar pond or a flat-plate collector. Concentrating or focusing collectors are devices made to track the sun. Some are parabolic or dish-shaped; some incorporate mirrors to reflect sunlight upon central receivers. Concentrating collectors are capable of producing high temperature. A solar pond is shallow water usually lined with black plastic and filled with salt water.

Water serves as the heat transfer medium for flat-plate collectors used to power irrigation pumps. After the fluid is heated, it is circulated through a closed system. Its flow is controlled by temperature sensors and valves. When heated to a prescribed temperature, the water passes through a heat exchanger. In this process, it heats another fluid, the working fluid, which is contained in another closed but pressurized system. The working fluid is then vaporized into a gas. The expanding gas drives a turbine water pump or an electric generator. As the gas cools, it changes back to a liquid state and is returned to the heat exchanger to complete the cycle.

If conveniently located, a generator can produce electricity for other uses when not providing power to operate irrigation pumps. If not needed on the farm, excess electricity can be fed into the grid system and sold to an electric utility company. In some cases, excess solar energy (electricity) can be supplied to neighboring farms.

Another alternate energy approach is the use of a solar-powered Rankine-cycle irrigation pump *(8)*. The system, tested by Barber-Nichols Engineering Co., Arvada, Colo., consists of two major subsystems: the solar collector and the Rankine engine. The collectors used in this project, Del Manufacturing (Los Angeles) and Solar Kinetics (Dallas), serve as the engine boiler. This boiling-in-collector concept has three benefits: simplicity in controls needed to prevent overheating of the oil, cost savings in the number of heat exchangers required, and improvement in engine efficiency.

Results showed that the boiling-in-collector system had a 10- to 20-percent cost advantage over conventional Rankine engine systems using organic working fluids. However, even though this study provided proof of concept, questions remain concerning the measured collector efficiency.

DOE's Division of Solar Technology and the Northwestern Mutual Life Insurance Company also have sponsored solar-powered irrigation research. Four major designs are being demonstrated for dispersed onfarm solar irrigation systems *(1)*. Three of them rely on a field of concentrating collector-receivers (table 9). These collector-receivers capture direct insolation and use it to raise the temperature of a heat transfer fluid. Next, energy in the heat transfer fluid is converted by a heat exchanger to a working fluid for the Rankine-cycle turbine. The turbine, then, either delivers shaft mechanical power directly to an irrigation pump or electric power to a motor-driven irrigation pump. The fourth system, shown in table 9, uses two rows of photovoltaic panels. They convert insolation to electric power, which, after passing through the battery storage system and a dc-ac inverter, is delivered to a motor-driven irrigation pump.

The initial Willard, N. Mex., system was upgraded by adding low-energy, center-pivot irrigation; an additional 7,000 ft^2 of solar collectors; an additional 6,500 gallons of heat transfer fluid thermal storage; and an electric generator to allow year-round operation. The farmowner built a 50,000-hundredweight (cwt) potato warehouse adjacent to the solar collector site, so that it could be air-conditioned by the electric power produced.

Table 9—Summary of solar-powered irrigation system characteristics

Location of system	Sponsor or system	Type of collector array	System function
Schrimpsher Bros. Farm, Willard, N. Mex.	Sandia Laboratories, Albuquerque, N. Mex.	Acurex distributed linear concentrating focus, parabolic trough; 6,720 ft^2.	Pump irrigation water from 110-ft deep well to 4.5-acre-foot pond; air-condition 50,000-cwt potato warehouse.
Dalton Cole Farm, Coolidge, Ariz.	Sandia Laboratories, Albuquerque, N. Mex.	Acurex distributed linear concentrating focus, parabolic trough; 43,200 ft^2.	Pump irrigation water from three deep wells at rates of 285 to 780 gallons per minute; 390-foot lift; 24 hours per day; produce electricity.
Gila River Ranch, Gila Bend, Ariz.	Northwestern Mutual Life Insurance Co.	Hexcel distributed linear concentrating focus, parabolic trough; 5,500 ft^2.	Delivers 5.6 x 10 gallons of irrigation water on longest days in June, powering 50-horsepower motor for 9.5-hour period.
Univ. of Nebraska Experiment Station, Mead, Nebr.	DOE and Massachusetts Institute of Technology Lincoln Laboratories.	28 flat photovoltaic panels with 656 Solarex and 1,248 Sensor Tech Modules; 120,000 circular silicon cells; 6,000 ft^2.	Pumps 1,000 gallons per minute reservoir water to irrigate 80 acres of corn and soybeans; powers 2 to 5-horsepower fans for grain drying, 12 hours per day.

Source: *(8)*.

Near Coolidge, Ariz., a concentrating solar collector supplies 150 kilowatts of electricity for pumping water from a depth of 390 feet. A field of 384 parabolic trough collector modules captures the sunlight by focusing it onto receiver tubes which run along the axis of the collectors and heat an oil-based fluid to 550°F. The heated fluid is used right away or stored in a tank for up to 6 hours of operation. In either case, the hot fluid is used to vaporize another low-boiling-point organic fluid, toulene, which drives the Rankine-cycle turbine to generate electricity.

The facility located on the Dalton Cole farm is the world's largest solar thermal power plant *(93)*. Built by Acurex Corp., it contains 43,200 ft^2 of Acurex-supplied, line-focusing parabolic trough collectors. The solar collectors are oriented in a north-south direction to maximize summer energy collection for irrigation needs. The system has demonstrated the practicality of applying a solar-thermal electric system to process heat and electrical generating systems for industry as well as for agriculture. When generated power is not needed for irrigation it is fed into the grid network of the local ultility, thus increasing the value of this photovoltaic system.

In its first year of operation, the Coolidge system generated up to 22,000 kWh of electricity per month, driving three deep-well irrigation pumps which watered 200 acres of cotton. Results for the first year of operation show an annual average collector field efficiency of about 20 percent at design temperature with daily average efficiencies reaching 30 to 32 percent around the summer solstice. The amount of collected thermal energy, as a percentage of available direct radiation during the spring and summer of 1980, was:

March	20.6	June	32.5
April	28.2	July	32.3
May	30.6	Aug.	29.6

Costs associated with the Coolidge, Ariz., system illustrate three things common to nearly all solar thermal technologies—high initial investment cost, low operating cost, and rapid progression down the learning curve (see the Cost Reductions section). The total cost incurred for the design, procurement, construction, and startup of the facility over a 2-year period ending Sept. 30, 1979, was more than $5.5 million. The same system, if built in 1981, would cost $2.6 million because of the experiences gained over the period with similar systems. Annual operating costs for the system, less labor, totaled about $1,700. Operating expenses averaged $78 per week in the summer during irrigation but only $26 per week in the winter when power was being fed into the grid network. Labor requirements averaged 30 hours per week—4 to 5 hours per day—in the first year of operation. This labor requirement is expected to decline as automation features are installed. Operating material costs also may decline somewhat.

Researchers at the Coolidge, Ariz., site also may install a grain alcohol facility. Onsite alcohol production could use a portion of the energy collected by the solar collector, leading to a nearly energy self-sufficient farm.

At first, the Gila Bend, Ariz., system demonstrated that the use of solar energy for powering irrigation pumps was technically feasible, but the system's operation did not coincide with irrigation practices of the region. As the sole source of power for pumping, the system was incapable of supplying a constant flow of irrigation water. Thus, it had to be supplemented with electric power.

The Mead, Nebr., research project is a 25-kWh-peak solar photovoltaic power system. The initial application of this system provided power to irrigate an 80-acre cornfield, and was later expanded to include experimental crop drying and fertilizer manufacturing. Fertilizer manufacturing provided a use for the system's surplus electricity during those portions of the year when irrigation and crop drying were not required. However, the fertilizer experiment was found uneconomical and was discontinued in 1980. The Nebraska project later was expanded under the DOE-sponsored Energy Integrated Farm Systems project to simulate an energy self-sufficient farm.

Progress at the Mead, Nebr., site suggests that photovoltaic-powered irrigation pumping is technically feasible. Technological changes that will result in cost reductions are still being made. For example, close attention is being paid to the efficiency of the electrical system that presently converts dc into ac. If dc can be used to power the irrigation pumps, the system can be run cheaper while avoiding about a 10-percent power conversion loss.

Solar-powered irrigation is currently feasible only in remote areas not served by electricity. However, during 1975-80, the DOE Photovoltaic Energy Systems Program, together with industry efforts, achieved significant cost reductions. Cost reductions in the next 5 years are expected to lead to costs competitive with current utility charges *(103)*. DOE goals call for cost reductions from $10 per peak watt (1977 dollars) to 50 cents per peak watt in 1986.[16]

Progress of the three concentrating collector projects is also largely dependent on cost reduction. General progress, to date, on these systems suggests that:

- A small segment of the irrigation market will become available for penetration in 1985 on large farms in southeastern Arizona. A substantial portion of the market in the 17 Western States could be avilable for penetration if present collector cost estimates of $14/ft^2 could be cut in half by 1985 (1977 dollars).

- Cooperatives servicing a large irrigated farm community could be the first market penetrated because farmer-owned, power-distributing cooperatives have comparative lifetime costs considerably lower than the smaller onfarm solar irrigation system applications.

- Differences in taxation and interest rates will make the type of ownership of solar irrigation systems a strong

[16]For residential uses, the photovoltaic program cost goals for 1980 called for modular prices of 70 cents per peak watt and system prices of $1.80 to $2.20 per peak watt *(107)*.

factor in establishing a competitive position with conventional irrigation systems; for example, the owner of a large farm, with high earnings and access to favorable loan rates, would be more inclined to consider a solar-irrigated system than the owner of a small farm.

- Initial penetration of the irrigation market by small onfarm solar energy systems will be encouraged if a nearly uniform energy demand exists throughout the year. If solar-powered systems service only seasonal irrigation needs of the farmer, their cost competitiveness is largely diminished. The simplest means to negate this prospect is to use out-of-season, solar-generated energy for non-irrigation purposes or to sell it to utility companies.

Solar Distillers and Dehydrators

Solar stills capable of distilling alcohol solutions from fermented liquors are being demonstrated frequently at energy fairs throughout the Midwest. The economic feasibility of these devices has not been verified. One of the more promising sun-powered stills on the market was designed by an Australian scientist. It consists of a 36-ft^2 flat-plate collector mounted on top of a fractional distillation plant. This liquid-medium collector has the capacity to produce 1,200 gallons of alcohol fuel per year *(46)*.

Flat-plate collectors are also being tested for use in drying stillage (wet byproduct of the distilling process), reducing it from about 60- to 90-percent dry matter. These collectors are also being designed to assist methane generators. These uses, while not conventional, could have potential especially if farmers strive for energy self-sufficiency.

Hansen and Grenard at Colorado State University concluded that a \$29/ft^2 solar collector drying system used to dehydrate alfalfa for a 150,000-bird broiler operation was close to being economical *(32)*. Alfalfa tops and leafy portions were dried in a batch-type drum dryer heated by an air-type solar collector. Cost estimates for the drying system showed that use of the collector yielded an estimated 13-percent rate of return. The researchers also concluded that the feeding quality of the solar-dehydrated alfalfa was similar to high-temperature gas-dehydrated alfalfa, but that low-temperature solar drying resulted in more protein retention. (The engineers conducting this study assumed a 25-year collector life and a cost of only $20 per ton dry basis in the field for the alfalfa.)

Residences

The residence is the most easily modified farm structure for alternate energy needs. In a year's time, the average farm residence will use about 150 million Btu of energy. Most farm residences are heated with fuel oil (42 percent), natural gas (30 percent), or LP gas (17 percent). A few are heated with electricity (11 percent), although many use electricity for air-conditioning.

Although home energy consumption is a consumer good as opposed to a farm production item, economics may force a fusion of the two uses. Joint use possibilities confound market analysts since farmers' decisions to procure production items are based on profit considerations, and their decisions to buy consumer goods may be sometimes less rational. Nevertheless, if joint uses are required to make solar collectors an economical choice, then the solar industry must learn to handle this dual demand, just as the automobile industry learned to sell vehicles for joint business and personal uses.

Space Heating. Because of the long hours required for home space heating and domestic water heating, these residential uses represent one of the most economical applications of direct solar thermal energy systems on the farm. Payback, especially with existing residential energy tax credits, is under 5 years for some low-cost and efficient systems.

Both air-type and liquid-type solar collection systems are on the market. Farmers may also choose between commercial and homemade collectors.[17] These collectors may be mounted on or built into the roof or placed on the ground adjacent to the house. The latter may be permanent structures or portable.

The rapid payback of flat-plate solar collectors used only to heat residences suggests using stationary-type collectors. Home orientation (a south-facing roof), the size of collector needed, and other uses may be the factors that determine whether a solar collector is placed on the roof or on the ground. Space is no problem for ground-based collectors in most farm situations. However, if farmers choose home space heating as a method of achieving greater use for their solar collectors, then the collectors probably should be portable. Such multiple-use decisions enhance other uses, making the collector more economical by spreading fixed investment costs.

Because of farm enterprise mix (number and type) and other factors, there are many farms on which dedicated residential systems—systems designed for one use—may be most practical. Also, allowable tax credits are extremely important in achieving acceptable payback periods for residential solar space-heating systems. Federal residential energy tax credits have been increased to 40 percent for the first $8,000 of qualifying solar equipment. The addition of State energy tax credits pushes that total to as much as 70 percent.

If multiple-use collectors are used more than 80 percent of the time for residential purposes, then they are considered by the Internal Revenue Service to be used entirely for residential purposes, thus qualifying for full residential energy tax credit. If a collector is used less than 80 percent of the time to heat a residence, then credits must be allocated in proportion to the use.

[17]Wood undergoes extreme punishment when exposed to the sun, water, or other weather conditions. It has shown signs of thermal deterioration when used in collector frames and charring when used in some collectors. Only treated woods should be used in collector mountings on rooftops. Homemade collectors mounted on the top of homes should be made of noncombustible materials.

Full tax credits are allowable only on commercial collectors. Energy tax credits are not allowable on the value of the owner's labor or on any used materials included in collector construction. Some States will not allow energy tax credits on homemade solar collectors unless their value can be certified.

Hot Water. Hot water systems are among the simplest and most efficient applications of solar heat. Payback may be well under 5 years. The length of payback, of course, depends on the type of fuel being replaced. Approximately 60 ft^2 of flat-plate collector surface can provide 60 to 80 percent of the annual domestic hot water required for a home (80 gallons of daily hot water use).

An estimated 80,000 solar hot water systems, both dedicated and integrated with solar space-heating systems, were operating throughout the Nation in 1980 *(86)*. About 3 million ft^2 of solar hot water collectors were marketed annually in recent years, accounting for about 20 percent of all solar collector sales *(107)*.

Heated water is needed on farms for both residences and livestock. The relationship of hot water energy requirements to total energy needs for a residence and a dairy is as follows:

Residential energy use	*Percent*	*Dairy energy use*	*Percent*
Space heating	53	Water heating	24
Water heating	12	Milk cooling	21
Air-conditioning	8	Ventilating	17
Refrigerating	7	Milking	11
Lighting	5	Water supply	10
Other electricity	5	Lighting	9
Cooking	4	Feeding	5
Clothes drying	1	Waste disposal	1
Other	5	Other	2
Total	100	Total	100

Solar water-heating technology has become an economical energy alternative in most homes. A comparative study of six generic solar domestic hot water systems by the Solar Energy

Research Institute (SERI), Golden, Colo., found that the cost of delivered solar energy is much higher for double-tank systems than for single-tank systems, and direct-pumped systems are less expensive than indirect systems *(24)*. Air systems were most expensive.

The SERI study concluded that the thermosyphon system—one that used potable water as the heat transfer liquid—was the least expensive system due to its low initial cost and low parasitic energy consumption (conventional energy to run fans or pumps) (table 10). However, the lack of efficient and reliable freeze protection devices limits this solar hot water system to regions with warm climate.

A study of double-tank systems in five major cities found that the net cost of the solar system in the first year was zero because Federal tax credits were greater than expenses *(112.)*[18] From the second to the fourth year, solar energy costs were greater than the anticipated electrical energy costs. The break-even point occurred in the fifth year.

The same study showed a 5-year break-even point for integrated, liquid-type space and domestic hot water heating systems. These conclusions suggest that solar hot water systems may have about the same payback regardless of integration with space-heating systems. System choice may be a matter of convenience and installation space rather than economics.

Since most technology for solar water heating has been directed toward the development of liquid-type collectors, farmers can best minimize their costs by selecting manufactured kits rather than purchasing commercially manufactured collectors or attempting to build homemade units. With tax credits, payback to farmers in the Midwest may be as short as 2 years on manufactured kits if solar replaces electricity, and 4 to 5 years if it replaces natural gas-heated water.

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[18]Atlanta, Ga.; Washington, D.C.; Boston, Mass.; Hartford, Conn.; and Cleveland, Ohio.

Table 10—Comparative costs of six solar domestic hot water systems

System configuration	Assumed collector cost	Component cost: Collector	Storage tank	Pump, controls, solenoid valves, etc.	Miscellaneous	Installation	Total installed costs	Cost of energy over 20-year period
	Dollars/ft²	*Dollars*						*Dollars/mil. Btu*
Thermo-syphon	7.50	405	287	—	153	422	1,267	8.50
	15.00	810	287	—	153	625	1,875	12.50
Single tank:								
Direct	7.50	270	287	406	182	573	1,718	12.90
	15.00	540	287	406	182	708	2,123	15.94
Indirect	7.50	405	287	510	[2]396	779	2,397	17.14
	15.00	810	287	510	396	1,002	3,005	21.49
Double tank:								
Direct	7.50	405	537	406	202	775	2,325	17.62
	15.00	810	537	406	202	978	2,933	22.23
Indirect	7.50	405	537	510	416	934	2,802	21.99
	15.00	810	537	510	416	1,137	3,410	26.76
Air system	7.50	600	537	671	411	1,110	3,329	34.51
	15.00	1,200	537	671	411	1,410	4,229	43.84

— = Not applicable.

[1]The two figures presented with each configuration are the extreme costs averaged from several studies.

[2]As an example, this miscellaneous cost consists of $20 for copper tubing, $10 for gate valves, $250 for a double-wall heat exchanger, $15 for two relief valves, $24.50 for an expansion tank, $49.50 for three thermometers, $7 for an air vent, $10 for copper fittings, and $10 for antifreeze solution for a total of $396.

Source: *(24)*.

Potential for Market Growth

Recent progress in the development of solar technology suggests that farmers have several options. They may adopt technologies specifically developed for the residential or agricultural markets, purchase commercial collectors, or construct do-it-yourself homemade collectors. These alternatives will each, quite likely, command a share of the agricultural market.

Most farms, especially if diversified, have a host of power and fuel needs that the various types of solar collector can supply (fig. 5). These needs can be divided into two groups—stationary and mobile (fig. 6). The diverse applications of the stationary uses (hot water, space heat, electricity, and so forth) present farmers with several alternatives for solar energy systems. Nevertheless, mobile uses of energy (tractors, field machinery, transportation) account for nearly four-fifths of all farm energy used.

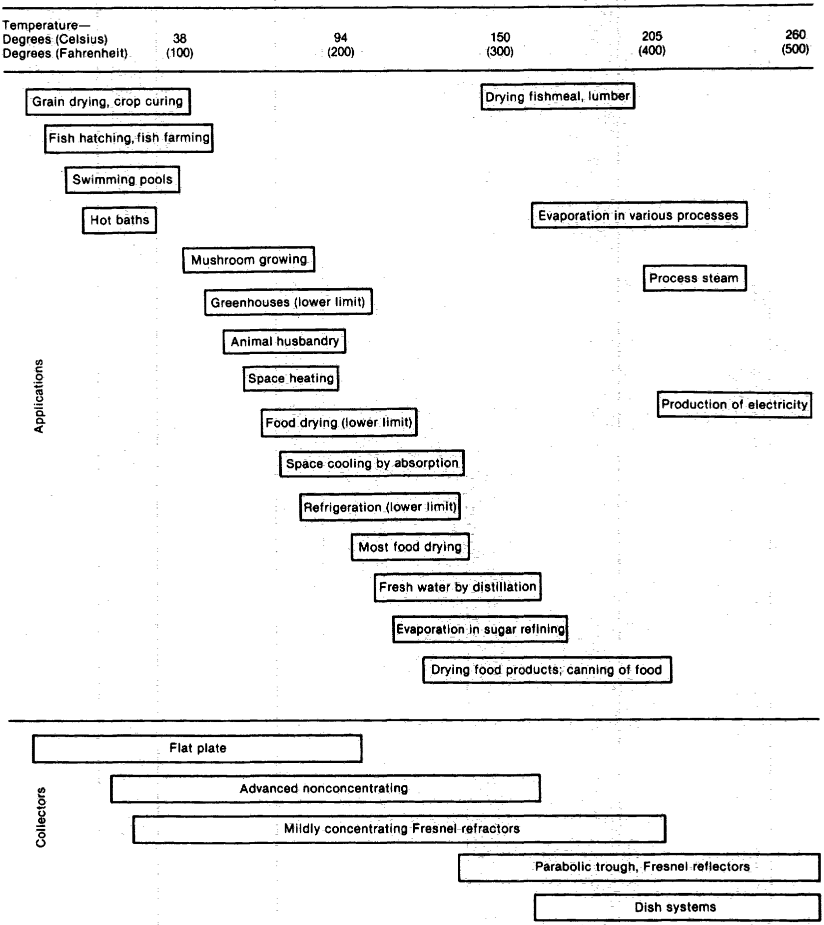
Stationary farm power and fuel needs account for about 22 percent of the total farm production energy requirements. In 1978, stationary farm energy requirements, excluding irrigation and the electricity required for lighting and powering appliances, totaled 198.8 trillion Btu (table 11). These stationary energy uses—home heating, crop drying, poultry brooding, and others—accounted for about 10 percent of total farm energy requirements. The demand for these uses increased at a rate of 1.1 percent, annually, during the late seventies.

The degree to which direct solar thermal energy will be used for stationary farm activities will depend on its competitiveness with conventional energy sources and also on the development of other alternate energy sources. Stationary farm energy needs can be met by direct solar thermal energy alone; by solar thermal energy combining with wind, biomass, or photovoltaic systems; or by any one of these alternatives.

The potential of direct solar thermal energy systems in agriculture is being studied by the Solar Agricultural and Industrial Process Heat (SAIPH) Branch, DOE. Its primary goal is the substitution of solar heat for fossil fuel wherever possible without

Figure 5

Required Temperatures for Various Solar Thermal Applications



Source: (98).

Figure 6

Classification of Farm Power and Fuel Needs

Stationary			Mobile
Milking machines Feeders Gutter cleaners Water pumps Lighting Egg candlers Elevators and augers Shop equipment Grinders Saws Welders ______ ______	Water heaters Stock tanks Dairies Domestic ______ ______ ______ Dehydrating Manure Stillage ______	Space heat Greenhouses Residences Dairy parlors Farm shops ______ ______ Brooders Chicks Pigs Lambs	Tractors Pickups Farm trucks Cars Self-propelled equipment Other: ______ ______ ______
Clothes dryers Clothes washers Cook stoves Refrigerators Freezers Sewing machines Misc.: small home appliances Egg coolers	Drying Grain Hops Tobacco Peanuts Raisins Onions ______ ______ ______ Electric fences	Ventilation and air-conditioning Farrowing houses Broiler houses Laying houses Frost protection Irrigation Other: ______	

Table 11—Type and quantity of conventional fuels used on U.S. farms, by major use[1]

Farm use	Fuel	Quantity
		Billion Btu
Home heating	Fuel oil	7,140
	LP gas	29,740
	Natural gas	36,680
	Electricity	2,350
Water heating	LP gas	2,100
	Natural gas	2,480
	Electricity	2,220
Crop drying	Fuel oil	8,613
	LP gas	57,904
	Natural gas	700
Livestock space heating and ventilating	LP gas	5,001
	Electricity	21,165
Poultry brooding	LP gas	19,835
	Fuel oil	1,230
	Natural gas	700
	Coal	943
Total		198,801

[1]Excludes fuel used for irrigating and greenhouse heating and ventilating.

Sources: *(92)*, and various U.S. Census housing reports.

intermediate conversion of the heat to electricity. The SAIPH program is concerned with food-processing requirements as well as farm needs. Food processing often requires hot water and steam. Thus, solar collectors producing temperatures of over 400°F are needed (see fig. 5). Most agricultural uses require lower temperatures.

As part of the SAIPH program, DOE has made the following estimates for the growth and use of solar energy for process heat:

- By 1985, solar energy could provide 1 percent of industrial energy and as much as 10 percent of agricultural process heat requirements.

- By the year 2000, with existing technology, 50 percent of the energy used by agriculture could be replaced by solar energy, and as technology for higher temperatures becomes available, solar thermal energy could supply 10 percent of industrial energy.

- By the year 2020, depending on technological advancement in the solar thermal electric field, solar energy could provide 20 percent of industrial process heat *(102).*

These estimates for agriculture are more optimistic than those made by the Energy Research and Development Administration (ERDA) in the midseventies which predicted that solar energy could supply 5 percent of the energy demand for agricultural purposes by 1985 and 25 percent by the year 2000 *(15).* The more optimistic SAIPH estimates may be related to much higher energy prices than were predicted by ERDA in the midseventies.

The potential market for direct solar thermal energy on farms may be much lower than the long-range DOE estimates because of the low ratio of stationary to mobile farm energy requirements. The upper limit may be 198.8 trillion Btu, or 10 percent of all farm energy needs. Realistically, the upper limit for direct solar thermal energy may be somewhat less than 10 percent by the year 2000. Direct solar thermal energy systems may be limited largely to crop-drying, water-heating, and space-heating needs. Requirements for lighting and power for appliances will more likely be met by conventional electricity or by electricity produced by photovoltaics. In addition, earth tubes and heat exchangers may supply some of agriculture's stationary needs.

Major Farm Uses

In terms of Btu requirements, grain drying and space heating offer the greatest farm production potential for solar energy (table 11).

Solar grain drying is apt to find greatest acceptance on farms where:

- More than one grain is produced,
- Harvest of a particular crop can be spread over more than 2 weeks and where custom harvesting is not practiced,
- Sufficient grain drying and storage space is available for maintaining shallow depths, not exceeding 5 to 6 feet,
- Grain is harvested at intermediate moisture levels,
- Layer-in-bin filling strategies can be used,
- Low-cost, homemade collectors can be built, using the farmer's own skill and labor, and
- Multiple uses can be found for the solar collector.

Solar grain drying will most likely replace natural-air or high-temperature drying systems using electricity or LP gas. Even if flat-plate solar collectors are found to be competitive with conventional drying methods their adoption still may be slow because often one major change in a farming system necessitates a chain of related changes. For example, solar grain drying may require slower harvesting and binning of lower moisture grain. Such changes in grain harvesting and drying are not likely to occur unless conventional fuels are no longer available or are extremely high priced. Therefore, solar technology is not likely to replace usable systems immediately. Instead, this technology likely will be given serious consideration only as farmers replace old and wornout grain dryers or expand their drying function.

The demand for solar space heating, both of livestock and poultry houses and farm residences, will likely increase as energy prices rise or new structures are built. Solar collector systems appear particularly suitable for air-conditioning climate-controlled housing.

Residential space heating and water heating represent large markets for solar collectors. Commercial liquid-type collectors are expected to fill a large portion of the farm residence demand. This potential consumer market will be penetrated regardless of the development of the farm production market.

In view of the rising world demand for food and limited cropland acres, the greatest potential for solar energy may be for growing vegetables in greenhouses and preserving them rather than for drying grain. Maes suggests that there is a huge potential for saving energy by the use of solar-heated home greenhouses *(56)*. Vegetable production, at or near its point of use, could save large quantities of high-grade energy presently used for transportation, processing, storage, and packaging—a potential for solar collectors not shown in table 11.

Solar gardening may involve greenhouses that are either unattached or attached to homes. A properly constructed greenhouse should have a positive effect on home space heating. However, there may be a conflict between the two objectives, solar grain and plant growth. Plant foliage must compete with direct storage mass for sunlight. If greenhouses are to have the potential suggested by Maes, they cannot be expected to serve effectively both as chambers for plant production and as passive heat sources.

Simple flat-plate, air-type solar collectors also can be used to provide heat for dehydrating (preserving) food produced in home gardens or greenhouses. Solar collectors that are attached to food-drying boxes require no fan. For most farm families, 10 to 12 ft^2 of collector surface per dehydrator is adequate. Heat naturally flows upward and outward—the chimney effect. These devices are called window box collectors because they are designed to heat one room, much like window air-conditioners. They can be built for $10 to $40 depending on the availability of used materials. They can be used throughout the winter to supply space heat either to the farm home, a dairy barn, or for other uses and in the summer to preserve food.

The potential for using solar energy for onfarm cooling needs is large. Summer ventilation needs have expanded with the emerging trend toward confined housing for livestock and poultry. Greenhouses also require some means of summer cooling. Other farm needs for cooling include the farm and the premarket preservation of milk, eggs, fresh fruit, and vegetables. Solar energy eventually may supply these cooling needs, but, at present, it is still uneconomical.

Three types of active solar cooling systems—evaporative coolers, absorption chillers, and solar/Rankine-powered chillers—promise success. Evaporative coolers are the oldest known solar-cooling systems, having found widespread cooling applications in areas of low humidity where it is possible to use the latent heat of vaporized water as it evaporates into the dry atmosphere to provide cooling.

Some scientists have applied solar energy to the operation of a Rankine-cycle engine to power chillers. Collected energy stored in hot water is moved through a heat exchanger where it gives up its hot energy to vaporize a working fluid. The vapor powers a turbine, providing shaft horsepower to supplement the shaft power of an electric motor driving the conventional air-conditioner. Though several prototypes of this system have been built, it is not an economical alternative at present.

Absorption chillers show the greatest potential, having emerged as the primary equipment in use for space cooling. The absorption chiller is a device built on the principle of a thermodynamic absorption cooling cycle, which is a heat-operated cycle. A secondary fluid (the absorbent) is used to absorb the primary fluid (the refrigerant), thus allowing the refrigerant to be transferred from the low-pressure side of the chiller to the high-pressure side. Main components of absorption cooling cycles are a generator, condensor, evaporator, absorber, and a solution pump (fig. 7.)

Flat-plate, concentrating, and evacuated tube collectors may each be used successfully to operate absorption chillers in space-cooling systems. Two types of absorption chillers, ammonia water and water-lithium bromide, are available commercially. These chillers have a maximum coefficient of performance of about 0.65, meaning that for every 1 million Btu of thermal energy applied to the generator, the chiller cycle will remove 650,000 Btu for cooling at the evaporator.

Chillers, engineered for solar applications, are commercially available in limited quantities for residential use, but are not yet economical *(4)*.

Substantial R&D efforts on residential absorption chillers are focusing on better adaptability to solar energy, coefficients of performance improvement, and initial cost reduction. Emphasis on air-cooled units for residential applications, 1- to 3-ton-capacity chillers, has led to a search for new refrigerant-absorbent chemicals.

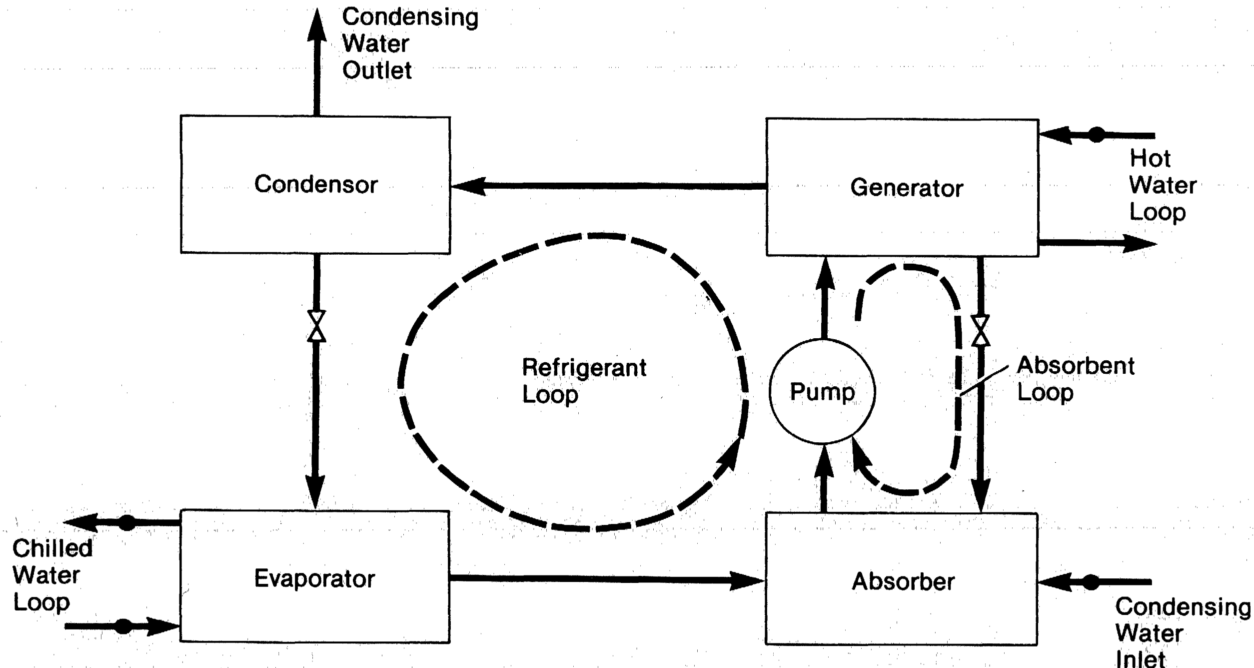
DOE-sponsored R&D is testing single-effect, water-lithium bromide, absorption chillers and searching for more efficient, lower cost refrigerant-absorption pairs *(7)*. Researchers are hopeful that solar collectors will be used in the large air-conditioning (cooling) market.

Cost Reductions

As solar R&D leads to improved performance, and the technology is better accepted by the public, manufacturers will likely devise methods of mass production. Labor input per unit of out-

Figure 7

Absorption Chiller Cycle of Operations

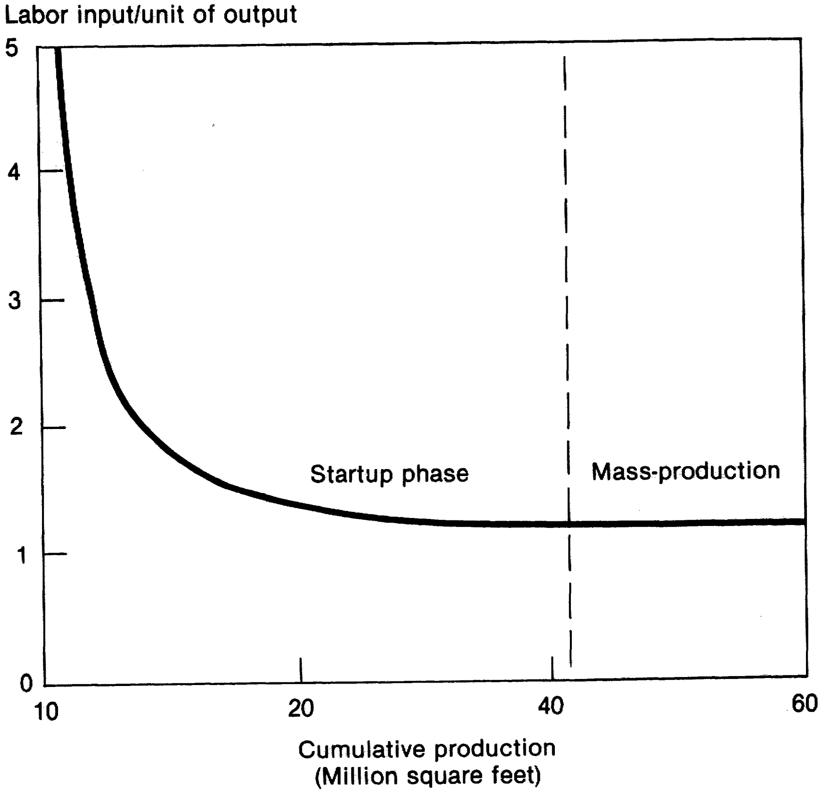


Source: (105).

put will then drop sharply, allowing manufacturers of commercial collectors to penetrate the agricultural market (fig. 8). This changing ratio of labor input to product output, known to researchers as a learning curve, is used to predict production costs *(6, 14, 52, 53)*.

Figure 8

Hypothetical Cost Reductions



Source: (52).

Once investments in plant and equipment are made for the manufacture of products like solar collectors, improvements in the production process are limited, coming thereafter only through retooling of the manufacturing process. However, managers still may learn to improve overall production efficiency by eliminating bottlenecks, rescheduling material deliveries, improving engineering, and substituting materials.

Homemade collectors may now be the most economical choice of farmers. However, farmers who build only one or two collectors will not have the opportunity to greatly reduce their construction labor time per unit. If all new materials are used and if the value of the farmer's labor is considered, unit costs of homemade solar collectors eventually could be higher than for mass-produced commercially manufactured collectors.

Threshold Prices

Energy prices increased drastically after the oil embargo in 1973 (fig. 9). In the 6-year period, 1976-81, prices increased as follows: retail gasoline, 138 percent; number 2 diesel, 183 percent; LP gas, 93 percent; residential natural gas, 334 percent; and electricity, 58 percent (see table 2).

Fuel prices paid by farmers in 1981 were generally higher than DOE's 1979 projections to 1995 *(101)*. Furthermore, prices of most farm fuels have escalated at rates considerably higher than inflation in recent years. Such increases, of course, favor the adoption of solar technologies. To be competitive with conventional energy sources, the annual cost of owning and operating solar collector systems need only approximate current energy costs. Investment costs locked in at 1981 costs will, in all likelihood, appear highly favorable by 1985 and beyond. A collector purchased or built in 1981 should have a 15- to 20-year life expectancy.

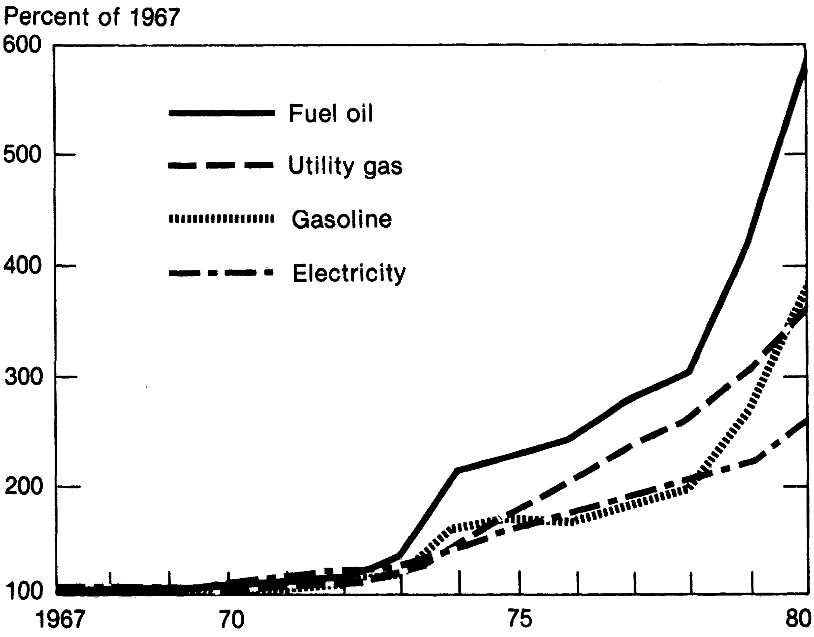
Once solar energy systems prove practicable, their use will depend on their economic competitiveness with conventional energy sources. A comparative economic measure is cost per million Btu. Threshold prices for 1981 ranged from $6.01 to $16.99 per million Btu, depending on the competing conventional energy source (table 12). If the total annual cost of producing a million Btu of energy with a solar collector exceeds these threshold prices, farmers are not likely to replace existing systems with solar. However, the availability of conventional fuels and expected price rises over the life of the solar collector also could enter into the decisionmaking process.

Market Penetration

The agricultural market stands to gain from cost reductions achieved through activities directed toward nonagricultural

Figure 9

Change in Energy Prices[1]



[1]Annual averages 1967-79; June data for 1980.
Source: (96).

Table 12—Threshold prices for economically competitive solar collectors, 1981

Replaced energy source	Units	Btu per unit	Typical efficiency [1]	Price [2]	Threshold prices
			Percent	*Cents*	*Dollars/ mil. Btu*
Gasoline	Gal.	124,300	90	129.0	11.53
Diesel	do.	138,690	90	118.0	8.01
LP gas	do.	92,000	90	69.9	8.44
Natural gas	Mcf[3]	10^8	75	451.0	6.01
Electricity	kWh	3,412	100	5.8	16.99

[1]In a normal farm use for which direct solar thermal energy may be substituted.
[2]See table 2.
[3]Million cubic feet.

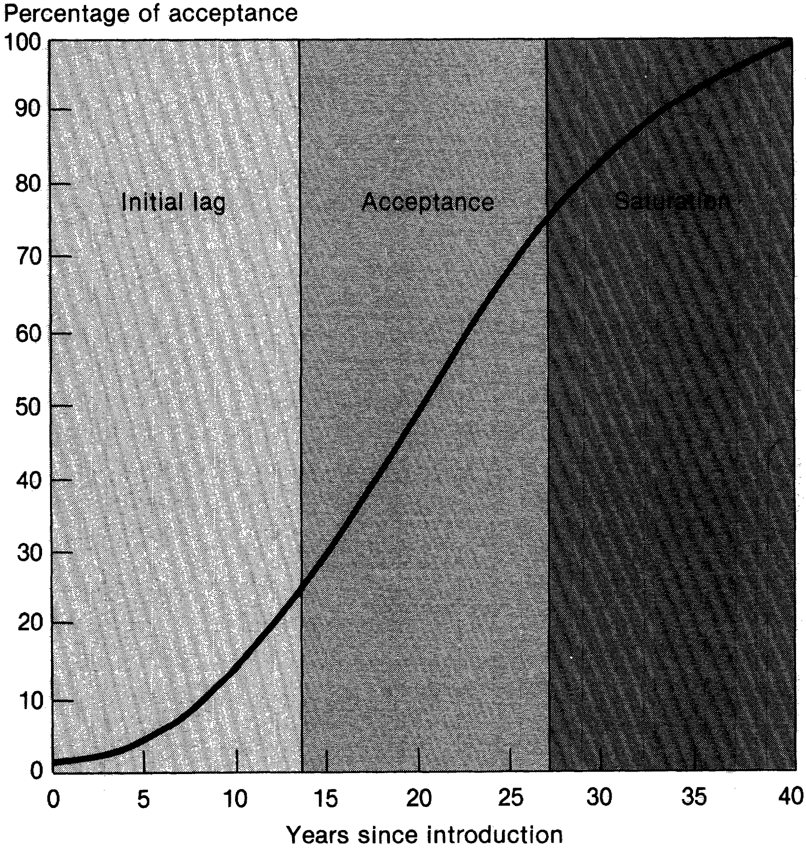
markets. Some solar collector systems designed for nonagricultural markets can be used directly for farm needs. Other new technologies can be transferred to agriculture and incorporated into the design and construction of homemade solar collectors.

Market penetration for solar technology is expected to follow the historical market penetration curve for other new products (fig. 10). R&D and commercialization activities of the seventies laid most of the groundwork for future market penetration. By the early eighties, these events have about elapsed the initial lag phase shown in figure 10. This phase, characterized by a large amount of government involvement and economic and institutional resistance, is rapidly ending. Government involvement in solar R&D is decreasing in favor of market development by the private sector.

Barring unforeseen extreme changes in the world energy situation, much of the potential for all types of solar technologies in agriculture and elsewhere will be met in the acceptance or "bandwagon" phase. This phase of market penetration will draw heavily on the imagination and initiative of private enterprise, especially considering the lessening of Government involvement.

Figure 10

Market Penetration Curve for New Technologies



Source (19).

The solar industry, through its sales, has entered the acceptance phase. The manufacture of solar collectors increased from 1.3 million ft^2 in 1974 to an estimated 19.4 million ft^2 in 1980 (fig. 11). Of the total 1980 sales, the agricultural market accounted for about 5 percent, the residential market for about 82 percent. Commercial, industrial, and government markets accounted for the remainder. Commercial sales for agricultural uses generally increased since 1974 but declined sharply in 1980. Conversely, sales of residential systems continued to increase, rising about 40 percent from 1979 to 1980.

Available financing, technical services, and product testing are signs of commercialization in the solar industry and are slowly building the confidence of farmers who can use commercial solar collectors. Conversely, the lack of these incentives for homemade-type collectors will slow farm market penetration. Little attention has been focused on the transfer of these technologies to farming applications. Most publicly supported solar promotional activities for agriculture have stopped at laboratory testing.

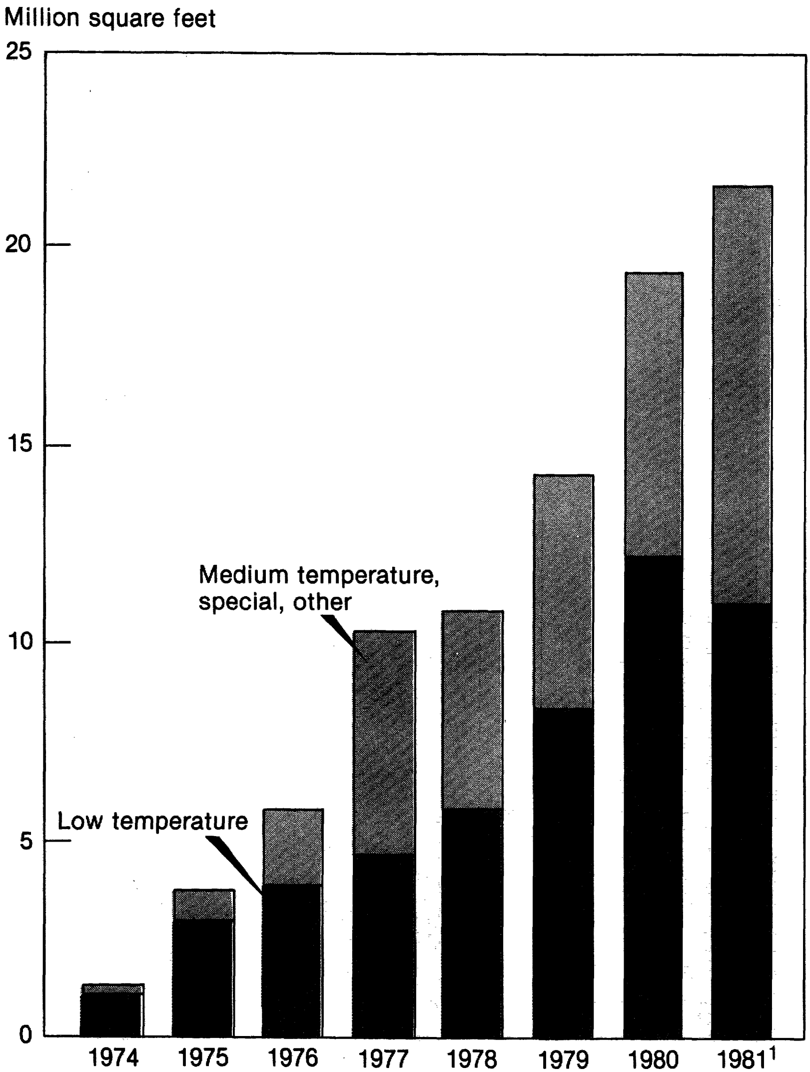
Before farmers can be expected to show widespread interest in low-cost, homemade collectors, a component marketing system must be developed. The performance and life of homemade solar collectors greatly depend on the use of specified materials or parts. Until such items as collector coverplates and absorption panels are commercially available, farmers and homeowners desiring to build their own solar collectors will not always be able to obtain the materials necessary for construction, nor will they select suitable materials.

Market penetration will move into the saturation phase as the technology is further perfected and as conventional energy prices rise above solar cost levels. As U.S. and world population grows, spurring demand for more energy and food, the market saturation phase appears both imminent and infinite.

By the early eighties, an infrastructure was forming rapidly in the commercial solar industry, consisting of product testing,

Figure 11

Solar Collector Manufacturing Activity



[1]Manufacturing activity for 1981 is an annual rate based on activity in the first 6 months of the year.
Source: (108).

Government incentives, advertising and promotion, trade associations, and a trained sales and service force—all developing into a well-rounded marketing system. As indicated by industry sales, this infrastructure mainly was serving the residential sector, but was also penetrating the commercial and agricultural markets. Furthermore, it was becoming international in scope. By the early eighties, the U.S. solar collector and component manufacturers had begun to compete in world markets with firms of other industrialized nations for a potentially large market, particularly in developing countries.

As part of DOE's commercialization effort, the U.S. role in international competition is being studied closely *(100)*. DOE is looking at what size of market the United States can expect based on past performance; the position of the United States relative to the potential foreign competition; and policy issues that will influence market size and market share.

In addition to foreign market identification and the encouragement of its development, U.S. policymakers are concerned with:

- Political and economic links with other industrialized countries growing out of collaboration in solar technology R&D,
- Political and economic relationships with those selected developing countries in a position to make significant financial or technical contributions to solar development, demonstration, and commercialization, and
- Relationships established with developing countries where U.S. assistance in solar energy supports the overall national development efforts.

Alternate Energy Sources

By 1990, competing alternatives may include solar thermal concentrating systems, photovoltaics, wind-generated energy, and certain biomass energy sources. However, considering inflation, a direct solar thermal energy investment locked in at early 1980 prices may remain quite attractive and competitive well past the advent of newer technologies. Adoption of a technology that has a life of only 15 to 20 years, but a payback of well under 10 years, still makes good economic sense even though it may be only a shortrun solution to high energy prices.

In the long run, direct solar thermal energy may continue to play a complementary role with wind and biomass energy sources as farmers seek to become energy self-sufficient. Some roles for solar collectors will be traditional; some will be created to accommodate other alternate energy activities. Farmers' attitudes may change in favor of solar collectors as the cost of conventional systems and fuel increases. Likewise, their attitudes may be affected by other economic changes such as the inflation rate, interest rates, and commodity prices.

Little is known about farmer attitudes toward using solar energy, types of systems demanded, or the number of systems already in use. It is a time of experimentation as well as confusion. Some commercial solar collector manufacturers are successfully selling their products to farmers. Several universities are offering plans for homemade solar collectors. At least one midwestern university is simultaneously promoting both homemade solar collectors and earth tubes for swine houses. Likewise, both solar collectors and heat exchangers are being recommended for heating water for farm dairies, and both solar collectors and passive attached greenhouses are being recommended for space heating farm homes. The USDA is sponsoring onfarm solar demonstration projects that promote both commercial and homemade systems. No organized solar education program, resembling the Energy Extension Service, exists for agriculture, and, thus far, little effort has been made to compare the economics of alternate energy sources.[19]

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[19]The Energy Extension Service primarily serves residential and small business interests, is sponsored by DOE, and is funded through State energy offices.

Thermal Concentrating Systems

Concentrating collectors are the most direct method of harnessing solar energy. By concentrating sunlight, high temperatures may be obtained, giving these devices a much broader application to agricultural needs than flat-plate solar collectors (see fig. 5).

Three classes of concentrating systems have been identified by DOE as having the potential to capture major shares of key sectors of the U.S. energy market: linear distributed receivers—parabolic troughs and hemispherical bowls, point-focusing distributed receivers—parabolic dishes, and central receiver systems *(110).* The suitability of these systems is based on their unique optical characteristics and modularity.

Higher grade energy systems, such as thermal concentrating systems, eventually may be economically preferable to flat-plate systems in some farm applications, especially for large-scale production. Concentrating systems using conventional materials (glass, steel, and concrete) can produce heat from solar radiation over a range of temperatures from ambient to more than 200°F. These systems, modular over a wide range of sizes, are directly adaptable to existing equipment and processes requiring steam and hot air.

Specifically, concentrating systems may be used to: provide high-grade heat for processing agricultural products, produce electricity for such uses as powering irrigation systems, provide heat and electricity for residential needs, produce hydrogen, and power processes for conversion and production of other fuels and chemicals for farm production needs.

Concentrating solar thermal energy systems also may be used to convert renewable resources such as water and waste organic materials (biomass) into fuels and chemicals. Concentrating thermal collectors have entered the residential and commercial sectors of the U.S. energy market and show high potential in other sectors. In general, DOE 1990 goals (1980 dollars) range from $1,000 to $2,500 per kilowatt, depending on system capacity. The lower end of this range roughly equals $5 per million Btu for heat, well within threshold price levels. This cost level also compares favorably to DOE goals of $5 to $10 per million Btu for fuel derived from thermal-chemical processes. These goals are based on market value and, in turn, provide a framework to establish targets for subsystem costs. The aim of DOE is to reduce the cost of heliostats, troughs, dishes, and other concentrators to $7 or $10/ft^2 by 1990 and 25 to 50 percent lower by the year 2000 *(99)*.

Irrigation Systems. Perhaps more research has been conducted on applying thermal concentrating systems to irrigation needs than to any other direct farm application. Irrigated crops are estimated to account for 14 percent of the value of all exported crops. The 17 Western States accounted for 83 percent of the Nation' s irrigated cropland, and because of deep-well locations, they consumed 93 percent of the irrigation energy, or 346.3 trillion Btu annually (table 13). Also, since these 17 Western States represent the higher insolation region of the country, solar thermal research programs were concentrated on this market (fig. 12).

Potential loss to the irrigated crop production sector, due to rising energy prices and possible shortages, could have an estimated $2- to $3-billion impact on the Nation' s balance of trade and on local economics. This has spurred interest in alternate fuels to power irrigation pumps. A DOE study of economic and market potential for solar thermal power systems began in 1977 *(111)*. Data were developed listing county-by-county acreage by crop, irrigation requirements pumping depths, power unit distributions, and water source—ground or surface. A computer program profiled energy demand, by month, for input into solar tradeoff studies. These data were aggregated to obtain total market potential. A screening process was employed to determine the geographical region(s) where solar irrigation systems should be most concentrated.

Market potential was estimated using a strategy of meeting a level, year-round energy demand and a corresponding baseline

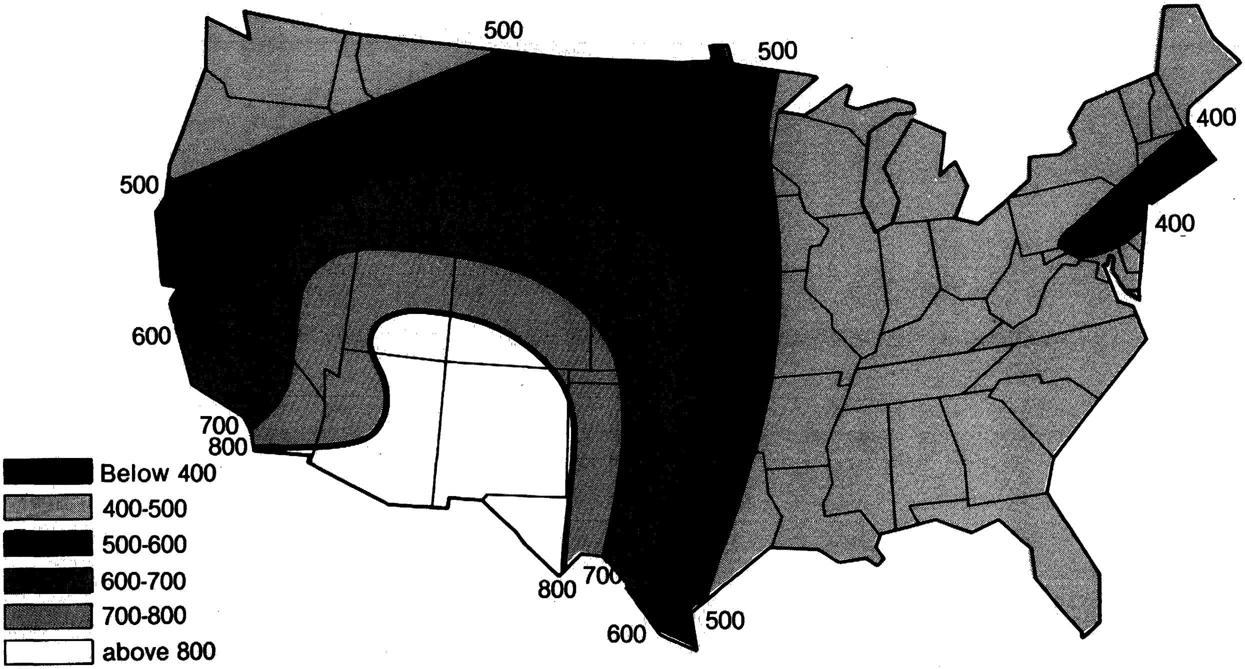
Table 13—Irrigation energy market demand summary, ground-water sources

State	Energy demand: Motor-driven pumps	Energy demand: Engine- and motor-driven pumps	Energy demand: Fuel energy
	10^9 kWh	*10^9 kWh equiv.*	*10^{12} Btu*
Arizona	3.38	7.15	42.4
California	4.91	5.27	54.5
Colorado	1.04	2.12	12.8
Idaho	3.58	4.07	40.0
Kansas	1.37	5.40	20.2
Montana	.32	.36	3.5
Nebraska	1.64	5.49	22.1
Nevada	.13	.21	1.5
New Mexico	1.31	4.54	18.5
North Dakota	.07	.12	.8
Oklahoma	.71	2.58	10.2
Oregon	.95	.95	10.4
South Dakota	.10	.30	1.3
Texas	6.25	22.11	89.7
Utah	.36	.50	4.1
Washington	1.00	1.00	11.0
Wyoming	.29	.42	3.3
Total	27.41	62.59	346.3

Source: *(111)*.

Figure 12

Average Annual Direct Insolation (1,000 Btu per square foot per year)



Source: (80).

solar cost of $4,700/kilowatt of energy (kWe) produced for an 80 kWe unit in 1985. The 17 Western States showed the greatest potential for applying solar thermal concentrating systems to irrigation.

A large farm market becomes available if solar irrigation system costs can be reduced to just under 70 percent of the estimated $4,700/kWe baseline system costs (point A), whereas costs must drop to under 60 percent of the baseline figure (point B) before the technology is economical for small farms (fig. 13). If system costs are reduced to 40 percent of current baseline system costs, nearly 80 percent of the large farms (point C) and 60 percent of the small farms (point D) become potential markets for solar irrigation systems.

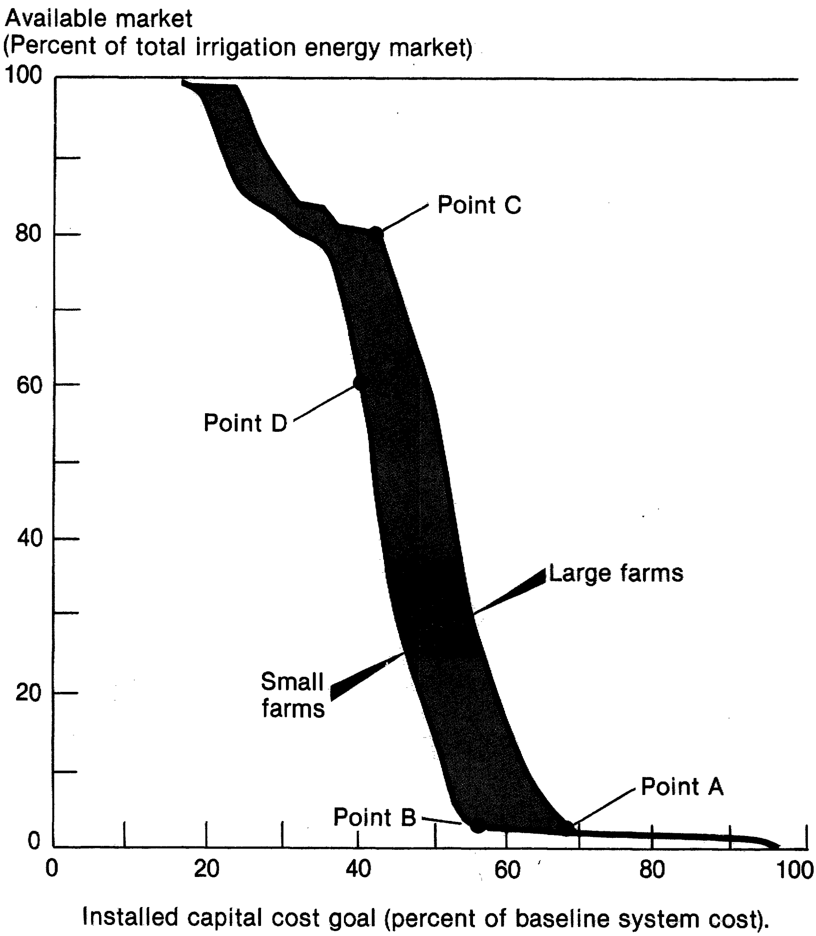
Photovoltaic Systems

Although electricity cannot be substituted for petroleum fuels in tractors, self-propelled combines, and other mobile field machines, it can be used for many stationary activities such as irrigation, crop drying, and feed grinding (see fig. 6). By 1980, about 8 percent of all the energy and power used on farms came from electricity. Electric energy in agriculture increased at almost twice the rate of all other energy demands. More important, this growth rate has not been related to the relative prices of alternate fuels as might be expected. The growth in farm demand for electricity is very similar to a trend in industry whereby electrically powered, automatic equipment has replaced much human labor. Since automation in agriculture has not reached its foreseeable limit, this trend is expected to continue. Farmers will likely never again, by choice, shovel the gutter, fork the silage, or carry the water.

As the demand for electricity grows, the potential for photovoltaic power systems increases. Photovoltaic systems can potentially produce electricity for nearly all stationary farm requirements. In a study prepared for DOE, the BDM Corp. identified more than 1,000 feasible, potential uses of photovoltaic energy

Figure 13

Solar Irrigation System Market Potential for Small and Large Farms



Source: (111).

systems *(113).* Of these, 122 were related to agriculture. They included:

Major energy end use	*Number*
Lighting	14
Mechanical drive	36
Electronic devices	21
Corrosion protection	21
Heating and cooling	20
Joint photovoltaic-thermal uses and other	10
Total	122

Market size was assessed and break-even system cost analyses were performed for the most promising of these systems.

Agricultural uses selected for detailed study included:

- Poultry, Athens, Ga.
- Poultry, Fresno, Calif.
- Hog production, Des Moines, Iowa
- Hog production, Bismarck, N. Dak.
- Beef feedlot, Fort Worth, Tex.
- Beef feedlot, Fresno, Calif.
- Irrigation, Phoenix, Ariz.
- Irrigation, Santa Maria, Calif.

Mengel and others of BDM Corp. chose the following conceptual designs *(59, 60):*

Farm	*Primary loads*
Poultry-layers	Ventilating, feeding, lighting, egg cooling
Hogs	Ventilating, space heating, brooder heating, pan cleaning, feeding
Beef feedlot	Feeding, watering, lighting
Year-round vegetable farm	Irrigating

They concluded that, for certain agricultural applications, photovoltaics are becoming potentially useful as an alternative to conventional energy sources. Photovoltaic systems, according to the BDM study, will be able to compete economically by 1986 with the utility grid for those farmloads which occur during the day, are relatively constant, or are independent of time. Irrigation and certain energy requirements associated with livestock production offer the greatest potential for photovoltaics.

The BDM study concluded as follows:

> The greatest potential application in the farm sector is irrigation, using dc current directly from the photovoltaic (PV). Assuming that all power produced is used for irrigation systems on a vegetable farm, the cost of the PV system is between 0.0894 and 0.1317 $/kWh. These prices are nearly competitive with the annualized cost of electricity from the grid at 0.08 $/kWh. The principal disadvantage of these irrigation system designs, both flat panel and fresnel concentrator, is their high capital cost of between $445,000 and $760,000. While generating between 0.778 mWh and 1.1 mWh annually, the initial system cost may be prohibitive.
>
> Poultry farming represents a PV application that is approaching economic competition with the cost of electricity. The combination of relatively high annual load requirements of 162,600 kWh and the high percentage of direct power factors enhances the potential of the poultry application, particularly if PV system's costs are reduced and fossil fuel prices continue to rise. In larger poultry systems, with an annual load of 165,045 kWh, the cost impact of utility buyback is of importance because these credits move the cost into the competitive range.
>
> Hog farms do not offer a particularly beneficial cost relative to irrigation and poultry. The percentage of direct power to the load ranges from 31 to 36 percent for the two flat panel and one line focus concentrator PV systems. Another line focus concentrator achieves 50 percent direct power to the load. Cost per kWh runs from 0.0848 to 0.1101 for the flat

panel and 0.2315 to 0.3568 for the line focus concentrator. Thus, even for the cost assumption with utility buyback, the line focus concentrator is not attractive. Conversely, the flat panel system is economically competitive, but the low percentage directed to the load detracts from the overall attractiveness of this application.

Continued advancements in photovoltaic technology could lessen the role of direct solar thermal energy in agriculture. The goal set by DOE calls for photovoltaic systems to produce electricity low enough in cost so that it can be grid-connected by 1986 and provide a significant percentage of the U.S. demand by 1990. To penetrate these intermediate and long-term markets, a multiyear program has been developed by DOE to reduce costs of systems, permitting rapid expansion of system production.

Although the emphasis is on long-term, grid-connected markets, a major effort has been directed toward the development of the stand-alone power market.[20, 21] One reason for the development of the stand-alone market is related to the high potential for photovoltaics in developing-country markets. However, both the grid-connected and the stand-alone systems have potential application for U.S. agricultural needs.

This technology is perhaps the most promising alternative to direct solar thermal energy, having far wider application potential than any other alternate energy source and causing the least disruption of present energy use practices (see fig. 6).

Currently, photovoltaic systems are economical alternatives for powering electric fences. They are replacing conventional electric fences on farms and ranches as well as on federally owned grazing land for powering remote livestock watering stations.

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[20]The photovoltaic system is connected to a public utility line, allowing the flow of electric current and the sale thereof to a utility company.

[21]A stand-alone power market is one beyond the reaches of public utility lines. A stand-alone photovoltaic system is one designed to supply the needs of a particular location. There is not opportunity to sell excess produced electricity from stand-alone systems.

The break-even cost for fully automated watering systems is about $25 per peak watt.

Diesel electric generator replacement (for stationary functions) is a major intermediate market for photovoltaic systems, which are competitive with 35-kilowatt diesel generators *(99)*. Within the next few years, 25- to 50-kilowatt diesel systems are expected to be economical.

At $25 to $35 per peak watt (1979 dollars), photovoltaic systems are competitive with gasoline-driven generators rated at 3 kilowatts or less when operating continuously. The same generators compete successfully with utility grid-extension lines for low-power requirements (less than 1 kWh per day) and long-line extensions of more than 5 miles. At costs of $10 per peak watt, these systems are competitive with most small gasoline-driven generators and with utility line extensions for residential-size loads (10 to 40 kWh per day) for line extensions of 2 to 5 miles.

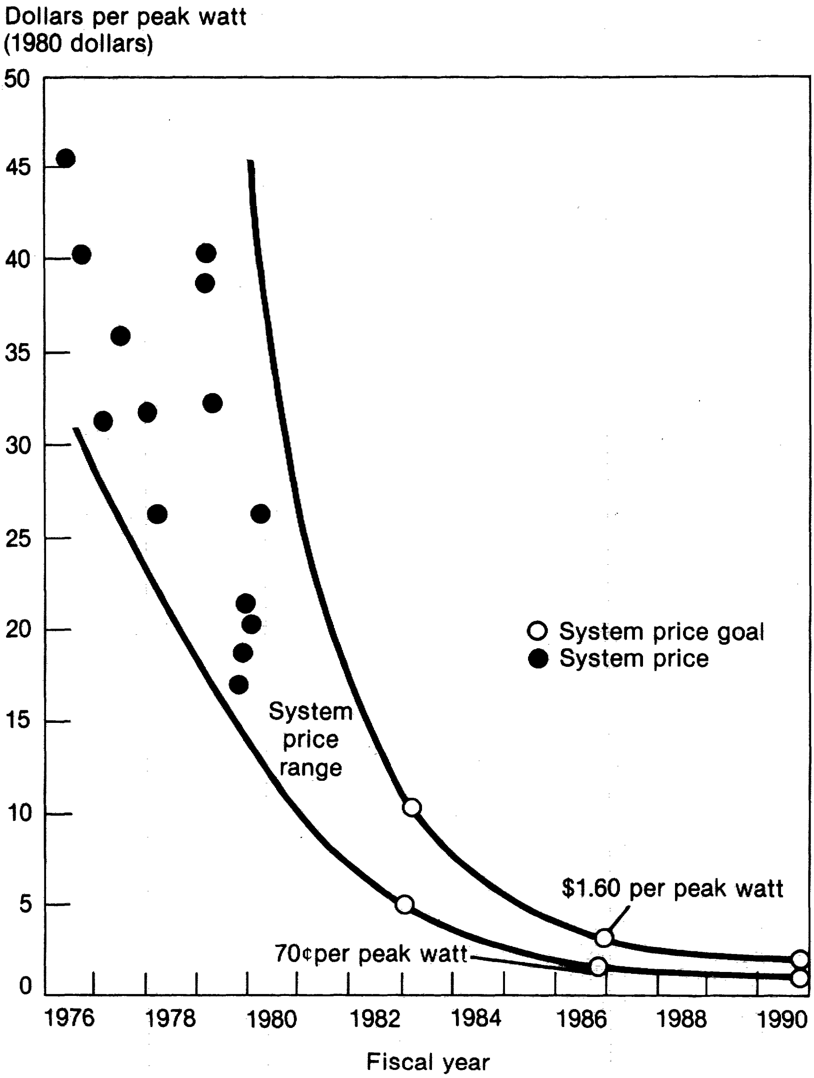
Steady progress in cost reduction, performance, and reliability made photovoltaic systems effective and economical for these uses by 1980. Solar cell modules for flat-plate arrays with efficiencies of 6 to 10 percent and early-life failure rates below 1 percent per year were available in 1980 at $7 to $15 per watt, when mass produced.

Government agencies have relied heavily on learning curves to predict the cost reduction potential for flat-plate photovoltaic cells. Through extensive subcontracting in each step of the array production process, DOE has successfully reduced manufacturing costs. Research by Jet Propulsion Laboratory (JPL) and others has kept the photovoltaic program on target for achieving the $1.60-per-peak-watt goal by 1986 (fig. 14). The learning process curve has been accurate to date, leaving JPL and others optimistic that further goals can be achieved. However, work remains to reach the 70-cents-per-peak-watt goal.

A strong ongoing development program emphasizes light concentration systems (concentrators) for solar photovoltaic cells.

Figure 14

Range of Photovoltaic System Prices



Source: (104).

Concentrator systems have generally been more costly than flat-plate photovoltaic systems, but these costs also may be reduced. The objective of this program is to reduce the cost of concentrator arrays by replacing the solar cell area with lower cost reflective or refractive materials and systems *(104)*. Lenses are focused on solar cells at the focal point of the system to increase net efficiency. Research by Sandia Laboratories shows that for 15-percent array efficiency, installed collector costs of $1,940/ft^2 can meet the 1986 goals of 70 cents-per-peak-watt equivalent without the use of thermal energy. Using thermal energy, this cost can be as high as $3,230/ft^2 and still achieve the 70 cents-per-peak-watt goal.

Industry sources say that, in the eighties, the industrialization of photovoltaics will proceed rapidly—that photovoltaics is coming of age *(54)*. An indication that this industry is about to develop into a major industry is the merger and acquisition activity. Oil companies own virtually all of the larger firms that manufacture photovoltaic cells *(42)*. According to *Solar Age* magazine, R&D is moving toward the DOE 1986 goal of having complete systems offered for sale by private manufacturers at $1.60 per peak watt (1980 dollars). For farmers and other rural homeowners, this means solar electricity delivered at a cost competitive with conventional electricity generation, transmission, and distribution *(49)*.

Connections with Public Utilities

Section 210 of the Public Utilities Regulatory Policies Act of 1978 (PURPA) defines how electric rates will be determined when a small power producer sells electricity to an electric utility and/or purchases electric power. PURPA says a small power production facility "produces electric energy solely by the use, as a primary energy source, of biomass, waste, renewable resources, or any combination thereof." By definition, both direct solar thermal and photovoltaic systems are included under PURPA, which states that a small power production facility can have a capacity of 80 megawatts or less. Systems designed for farm applications, including the farm home, have no problem meeting the maximum size requirement. PURPA also sets guidelines for sales between utilities and independent small-scale power producers *(21, 66)*.

PURPA provides an incentive to owners of private, small, electricity-producing solar systems. Such systems neither require the utilities to subsidize them nor cause consumers to pay higher rates because they can be interconnected with the utility grid system. The important factor with regard to agriculture is that connection with a utility can improve payback on small alternate energy systems. Though few, some farmers were selling excess power to public utilities in 1980. This practice may be expected to grow significantly by the end of the decade.

Conclusions

The first energy crisis of the seventies and rapidly advancing fuel prices stimulated interest in solar and other alternate sources of energy. The momentum achieved by solar R&D efforts during the seventies could be continued into the eighties, and solar energy could find widespread acceptance in U.S. farming systems.

Nearly a decade of pass-through funding from DOE and its predecessor agencies to USDA led to active R&D programs in the middle and late seventies. This research was aimed at agricultural applications, a market with different needs than residential markets, and one largely ignored by private industry.

The agricultural solar program focused on low-cost homemade systems. At first, research efforts were directed toward single-purpose, dedicated systems. Later, multiple-use systems were designed, mostly out of economic necessity. Systems were developed and laboratory tested at numerous Federal laboratories and land-grant experiment stations. In 1979, the USDA's Extension Service initiated a 3-year onfarm demonstration project for solar livestock systems. A year later, the agency started a similar project for solar grain drying. The solar grain-drying systems were required to have multiple uses. In both projects, farmers selected their cost-shared systems (either homemade collectors or purchased commercial units) and Extension agricultural engineers monitored system performance.

Simultaneously, during the seventies, private industry R&D reflected rapid progress, primarily toward the development and mass production of residential solar collector systems. Public funds supported much of this R&D activity. Nevertheless, the cost of most commercially manufactured solar collectors on the market in 1980 was double that of constructing homemade collectors, and often the commercially manufactured systems were not designed for agricultural uses. Also, the potential for cost reductions through mass production had not yet been realized by 1980.

Progress in the residential section, of course, applied to farm homes as well as urban ones. In limited cases, private industry attempted to develop technologies for broader agricultural applications. However, a combination of factors precluded it from adequately serving the agricultural demand: the lack of flexibility in design, allowing collectors to be applied to multiple uses; high investment costs; and lower energy tax credits for business (farm) applications than for residential use. Therefore, few commercial collectors for agriculture have a payback of less than 10 years.

Beginning in the eighties, Federal funding for solar energy research decreased sharply. No distinction was made between agriculture and nonagriculture solar R&D. This study suggests that the results of reduced funding could be totally different for the agricultural sector than for the residential sector. Progress in residential applications of solar was sufficiently advanced by the eighties to have established a well-organized network of manufacturers, dealers, and service as well as recognized collector testing, labeling, and warranties. Both private and public stock corporations made and sold solar collectors. Competition appeared keen with considerable merger and acquisition activity occurring.

In sharp contrast to the residential market, by the early eighties, farmers were just beginning to realize the agricultural benefits from nearly a decade of R&D work on low-cost collector systems. Although several systems offered reasonable payback, only a few plans were available to farmers, and only a few farmers had put solar collectors to use. Many laboratory systems still needed a thorough economic analysis. Furthermore, a method of certifying homemade collector value was still needed for lending and tax credit purposes.

The onfarm demonstration projects administered by the Extension Service were sharply curtailed by budget cuts in the early eighties, preventing specialists from properly publicizing the values of direct thermal systems.

Although some low-cost homemade systems are appropriate for agricultural needs, the transfer of this technology from laboratory to farm is highly dependent on public agencies such as the Extension Service. Otherwise, the technology languishes in the R&D stage. Little evidence exists that private firms have, or will, be interested in marketing the technologies developed for agriculture by the public sector. This, coupled with the cutback of Federal funds for solar R&D, may greatly slow the transfer of known technology and the adoption of direct solar thermal energy systems by farmers.

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Appendix: Sources of Information and Assistance

As solar technology advances and a solar industry develops, a large number of individuals and agencies will form a relationship of mutual interdependence. Creation of the wide spectrum of interests and sources of information is one of the first steps to industry development. MITRE Corp. prepared the following list of major participants *(38)*:

- End users
  - —Farmers
  - —Ranchers
- Solar equipment dealers and manufacturers
- Architectural and engineering (A&E) firms
- Mechanical contractors
- General contractors
- Financial Institutions
- Insurance companies
- Standards developers (nongovernment)
- Federal system integration agencies (USDA and DOE)
- Federal standards agencies (National Aeronautics and Space Administration, National Bureau of Standards, and National Science Foundation)
- State and local governments
  - —Cooperative Extension Service
  - —Taxing agencies
  - —Standards/code agencies
  - —Regulatory agencies
  - —Inspection and enforcement
- Professional and trade associations
- Solar associations
- Educational community
- Utilities

Of all the participant groups involved in solar energy, farmers, many times, have limited access to information. Yet, they require all of the information, incentives, product certification, and other ancillary services associated with a viable industry. Following are sources of information and assistance that may be useful to farmers considering solar technology.

Collector Testing Locations

During the initial survey of test facilities, several Government laboratories had the capability of testing flat-plate collectors to support low-temperature, solar thermal programs. The laboratories were:

Brookhaven National Laboratories—Has the capability for testing small areas of low-temperature, inexpensive collectors suitable for boosting heat-pump performance.

Lawrence Berkeley Laboratories—Maintains a test bed with about 40 square meters of flat-plate collector. Supports the development of control strategies for heating and cooling systems that use microprocessor programs and can be implemented in memory chips for mass production. Develops ammonia absorption cycle chillers capable of operating with low-temperature feedwater.

National Bureau of Standards Laboratory—Has loops designed for testing small areas of flat-plate collectors. Tests flat-plate collectors and develops standardized testing procedures which are used in establishing accepted test procedures such as those endorsed by the American Society for Testing Materials.

NASA/Lewis, Cleveland, Ohio—Operates a radiant-heat, general purpose facility with limited 1.2-meter by 1.2-meter aperture, and measures flat-plate collector performance under a variety of closely controlled input conditions, such as collector tilt angles and sun incidence angles.

NASA/Langley, Hampton, Va.—Has a large array (total 1,300 square meters) of flat-plate collectors supplying heating and cooling to a 5,000-square-meter building, and operates with near-ambient pressure water as a transfer fluid. Since the installation was originally designed as a collector test bed, it is well instrumented. Collectors from five manufacturers can be tested simultaneously, providing continuous data on individual collector performance.

NASA/Marshall, Huntsville, Ala.—Evaluates heating and cooling systems, subsystems, and selected components; committed to testing collectors from DOE demonstration programs.

All of these testing facilities are designed and operated for research purposes. Several other laboratories are capable of testing air collectors commercially in accordance with the requirements of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) 93-77, and Housing and Urban Development (HUD) document 4930.2. These laboratories should serve most of the needs of commercial manufacturers of flat-plate collectors. They include the following:

Boeing Aerospace Co.	Box 3999, Mail Stop 86-01 Seattle, Wash. 98124
Desert Sunshine Exposure Tests, Inc. (DSET)	Box 185-Black Canyon Stage Phoenix, Ariz. 85020
Florida Solar Energy Center	300 State Road 401 Cape Canaveral, Fla. 32920
CAL-SEIA	926 J. Street, Bldg. 1021 Sacramento, Calif. 95814
Mechanical Engineering Solar Testing Lab, Montana State Univ.	220 Roberts Hall Bozeman, Mont. 59717
New Mexico State Univ.	Physical Science Laboratory Las Cruces, N. Mex. 88003
Univ. of Connecticut	Solar Energy Evaluation Center U-Box 139 Storrs, Conn. 06268
Wyle Laboratories	Box 1008 Huntsville, Ala. 35807

Solar collector testing, certification, and labeling are becoming common in the solar industry. California, Florida, and two national associations, the Solar Energy Industries Association (SEIA) and the Air Conditioning and Refrigeration Institute, now have labeling programs. By April 1980, the Florida Solar Energy Center had certified 170 collectors from 90 manufacturers, including 42 from outside the State. The California Testing and Inspection Program for Solar Equipment (TIPSE) had certified 106 collectors from 47 manufacturers. An installation warranty program, conducted by the California Solar Energy Industries Association and the California Energy Commission, had registered 150 solar equipment installers and 650 systems carried their CAL SEAL label *(81)*.

For additional information concerning collector testing and certification, contact:

Guideline for Certification for Solar Energy Equipment (free)
CEC Publications Unit
1111 Howe Avenue, MS 50
Sacramento, Calif. 98925

SEIA Product Certification Standards 1-79 ($6.50)
Solar Energy Industries Assocation
Suite 800
1001 Connecticut Ave., N.W.
Washington, D.C. 20036

Underwriters Laboratories, Inc., (UL) has proposed, and soon will adopt, a set of standards for solar collectors. UL listing will be still another sign of progress in the solar industry. For more information on this testing program, contact:

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, Ill. 60062

Other Solar Data Sources

The solar energy industry could generate 3 million new jobs by 1990. Of these, about 1.7 million may be created for persons installing solar equipment. For information on energy careers, obtain:

> "Professional Energy Careers"
> DOE/OPA-0043 (3-79)
> Office of Public Affairs
> U.S. Department of Energy
> Washington, D.C. 20585

For information about upcoming agricultural and industrial process heat conferences and technological progress, contact:

> Agricultural and Industrial Systems Branch
> Office of Solar Applications
> U.S. Department of Energy
> Forrestal Building
> Washington, D.C. 20585

The Solar Energy Research Institute (SERI) publishes a solar events calendar which lists all conferences, meetings, courses, and seminars on solar energy conducted throughout the United States. The calendar can be obtained by writing:

> The Solar Energy Information Data Bank
> SERI
> Attn: Solar Events Calendar
> 1536 Cole Boulevard
> Golden, Colo. 80401

SEIA, representing 95 percent of the solar manufacturers, provides information to potential buyers on the location of manufacturers. SEIA's Division of Industrial Process Heat has information on the application of solar technology for various agricultural uses. It holds conferences throughout the year for members. These may be attended by other interested parties. They also schedule an annual trade show where 150 to 200 manufacturers exhibit their merchandise. For further information, contact:

Solar Energy Industries Association
1001 Connecticut Avenue, N.W.
Suite 800
Washington, D.C. 20036

The National Solar Heating and Cooling Information Center provides information on U.S. industries that are currently using solar technology, as well as information on solar energy consultants and publications. For further information, contact:

Solar Heating
P.O. Box 1607
Rockville, Md. 20850

The International Solar Energy Society has compiled a bibliography of solar material, ranging from introductory books to building design and engineering handbooks. This annotated list, which is updated as new publications become available, can be ordered for a minimal charge.

Bibliography
American Section of the International Solar Energy Society
300 State Road 401
Cape Canaveral, Fla. 32920

For information on various solar subjects, such as conceptional designs for small-scale photovoltaic, or solar thermal conversion systems sized to provide electricity for agricultural applications, and a listing of solar equipment approved under the National Bureau of Standards, contact:

DOE-Technical Information Center
P.O. Box 62
Oak Ridge, Tenn. 37830

For farmers with an engineering background who decide to build their own solar-heating system, the 4-volume ASHRAE Handbook can provide valuable data on system design. For further information, contact:

ASHRAE
345 East 47th Street
New York, N.Y. 10017

The Solar Energy Grain Drying Handbook was published in 1980 and has 86 pages. For a copy ($3.00), contact:

Midwest Plan Service
Agricultural Engineering Department
122 Davidson Hall
Iowa State University
Ames, Iowa 50011

Three other handbooks designed to assist the do-it-yourself builder are currently available:

Model-TEA Solar Heating System Construction Manual ($27.50)
Total Environmental Action, Inc.
7 Church Hill
Harrisburg, N.H. 03450
Pub.: 1980, 247 pages.

Portable Solar Collector Plans ($3.00)
Small Farm Energy Project of the Center for Rural Affairs
P.O. Box 736
Hartington, Nebr. 68739
Pub.: 1982, 34 pages.

Solar Air Collectors—A Design and Construction Guide for Low Cost Systems ($3.00)
San Luis Valley Solar Energy Association
P.O. Box 1284
Alamosa, Colo. 81101
Pub.: 1981, 28 pages.

For information on current solar research, development, and demonstration projects relating to solar, wind, and biomass, contact:

Southern Agricultural Energy Center
ARS, USDA
Coastal Plain Experiment Station
Tifton, Ga. 31794

For information on current research, development, and demonstration projects pertaining to the conversion of biomass products from farms and forests into fuel alcohol or other substitutions for petrochemicals, contact:

Energy
Northern Regional Research Center
ARS, USDA
1815 North University
Peoria, Ill. 61604

For information on the USDA solar demonstration farm projects, contact:

Office of the Administrator-Extension
Agricultural Research Service
U.S. Department of Agriculture
Washington, D.C. 20250

In addition to these sources, farmers and others interested in applying solar technology to agriculture can contact their local agricultural extension servivce, attend local energy fairs often sponsored by chambers of commerce or the farm news media, State fairs, exhibitions, and other farm shows. Most farm magazines attempt to keep their subscribers current on new energy technology. Other magazines are devoted entirely to energy, for example, *Solar Engineering Magazine* and *Solar Age*. SEIA, through its *Solar Engineering Magazine,* periodically lists manufacturers of solar collectors and related equipment.

Finally, a listing of personnel and telephone numbers of all State Energy Offices, Energy Extension Offices, and other State agencies concerned with energy is available from the U.S. Department of Energy:

The Energy Consumer
Office of Consumer Affairs
U.S. Department of Energy
Washington, D.C. 20585

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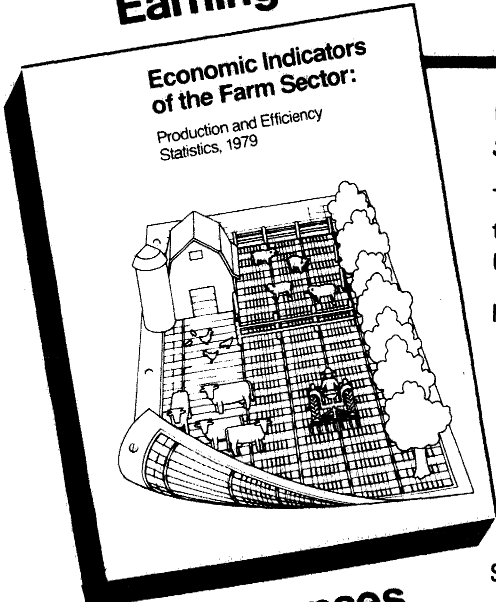

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